Real-Time Wireless Data Streaming in a PDA-Based Geographic Information System

By

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Real-Time Wireless Data Streaming in a PDA-Based Geographic Information System

By

Russell Lee Spieler

Submitted to the Department of Civil and Environmental Engineering
On May 10, 2002 in partial fulfillment of the requirements
for the Degree of Master of Engineering in
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ABSTRACT

A geographic information system for mobile data collection and wireless data distribution system was designed, developed, tested, and analyzed. The system allows field researchers to collect environmental data automatically from instruments and manually into a handheld computer. The system integrates this environmental data with geospatial data collected by an integrated GPS receiver. The data collected by this system is distributed wirelessly to a central location for real-time data sharing and access among users of the system, who may be at different geographic locations. The data is also distributed wirelessly to sponsors and the world via the Internet.

Field testing of this system as an environmental data collection tool lead to revisions and improvements. The system was compared to similar systems available in the market place. An analysis of this system's applications in fields other than environmental research was completed.

Thesis Supervisor: Ismail Chabini
Title: Professor of Civil and Environmental Engineering

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Biographical Note

As the author of this thesis, I like to provide the reader with information on where I draw my knowledge for this thesis and on where I may have short comings. As an undergraduate, I studied civil engineering with an emphasis on systems. As a result I took numerous courses which explored the use of computers and software in civil engineering projects. I also took a breadth of courses addressing civil and environmental engineering issues.

I believe that my extensive undergraduate course work in design provided a needed depth to carry out the work of this thesis. I designed civil systems, urban layouts, mechanical systems, and computer systems as a regular part of my coursework. I also completed a few courses that dealt specifically with transportation. This supported my work on adapting the STEFS system to transportation monitoring, as described in Chapter 9. In addition, I have completed an internship at Trimble Navigation, where I worked on the design of an automated GPS reporting unit for trucking logistics. Therefore, I have explored both wireless and GPS technologies prior to the project documented in this thesis.

Prior to my work on the project described in this thesis, my exposure to PDA's, mobile computing, wireless systems, databases and GIS (Geographic Information Systems) was limited to reading "Mobile Computing Magazine," and various articles on the Internet. I learned most of what I relate in this Thesis during my Masters of Engineering studies and effectively through the duration of the STEFS project. Therefore, I do not intend to be able to explain the intricacies of all of the alternatives I explored. Please assume that while the alternatives explored were likely

the most popular and readily available at the time of design of this system, they are by no means an exhaustive list of alternatives.

Please keep in mind that all of this was designed within a relatively constraining project budget and that all of it was part of a project organized as part of 25 students educations. These two factors often played a roll in selection of alternatives and design of the system. Finally, remember that the technologies and prices used in this thesis are rapidly progressing and the model numbers and prices quotes will probably be out of date even before this thesis is bound.

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CHAPTER 1: INTRODUCTION

1.1 Problematic

This thesis explores how to wirelessly transmit geographic information systems data from remote handheld computers to a distant fixed web server for processing and distribution on the Internet. It seeks to answer the question of how to transmit data from many handheld computers to a mobile field server. It also seeks to answer how to transmit data from the field server to a fixed web server thousands of miles away. It explores what software and data structures are required for this type of data distribution. It also explores how to associate location data with other data collected on the handheld computers and how to display that data on electronic maps. Finally, it seeks to explore how this solution compares with other solutions.

1.2 Background on the ENVIT (Environmental Information Technology) Student Group

The ENVIT (Environmental Information Technology) Student Group was formed at MIT (The Massachusetts Institute of Technology) in June 2001. The group's first project is a tool that allows environmental field researchers to enter data into a PDA (Personal Digital Assistant) both manually and automatically while taking readings in the field. This project called STEFS (Software Tools For Environmental Field Studies) was developed under a grant from Microsoft's I-Campus Project. ENVIT is an MIT ASA (Association of Student Activities) Recognized Group. ENVIT has program support from PEER (The Program on Environmental Education and Research) and financial support from the CET (Center on Educational Technology). This thesis investigates STEFS's hardware and software issues which allow for wireless transmission of data from the PDA's to servers and eventually to the Internet.

1.3 Motivation of STEFS (Software Tools For Environmental Field Studies) Project

The motivation behind STEFS is to allow environmental researchers to collect data using a PDA, integrated with automated sensors, and transmit that data live to the Internet. The idea is to move from the traditional field study where measurements are read by human eyes and reported manually, by recording data by hand on paper, to be later transcribed to a computer system and analyzed. Instead, STEFS seeks to automatically measure and log data into a handheld computer, transmit that data live to be processed, shared between researchers, and displayed live on the Internet.

Figure 1.1 gives a graphical depiction of the STEFS concept which is described in the next subsection.

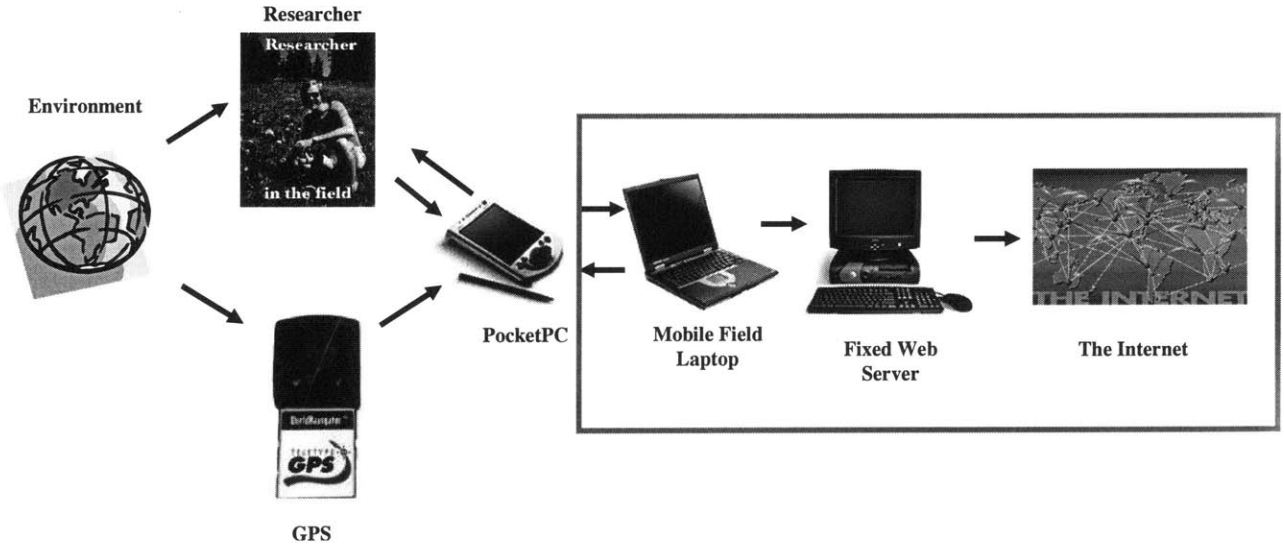


Figure 1.1: STEFS Concept

1.4 Overview of STEFS

Figure 1.1 depicts the concept of STEFS. It is a PDA based integrated wireless system. As shown, it allows field researchers to collect environmental and geospatial data and enter it into a handheld computer automatically or through a graphical user interface. The figure breaks the STEFS project into modules:

1. Sensors that collect environmental and location data automatically from the environment.
2. A graphical user interface (GUI) that allows the user to enter data manually.
3. The core of the system is a PDA which integrates the sensors and GUI.
4. Integrated with the PDA is both hardware and software that allows for wireless transmission of the collected data to a field laptop server.
5. The laptop field sever processes the data.
6. Integrated with the laptop is both hardware and software that allows for wireless transmission of the collected data to a fixed web server for display on the Internet.

This paper focuses on modules 4, 5, and 6 and explores how data is transmitted wirelessly to a field laptop where it is processed and transmitted back to the handheld computers for near real-time analysis as well as to a web server to share it with the outside world. This thesis documents the design, implementation, testing, and revisions to the core of this system.

1.5 Organization of STEFS Project Team

STEFS was designed as part of an Undergraduate Seminar and Masters of Engineering Project under the coordination of doctoral students, Enrique Vivoni and Richard Camilli. Four Professors and Staff, two doctoral students, six Masters of Engineering students, and thirteen

undergraduate students were involved in the design and implementation of this system. Together they spent over 6600 hours over thirteen weeks to create the system.

1.6 History of ENVIT and STEFS

Jan 2001	A proposal was written and submitted to MIT/Microsoft I-Campus to support the STEFS project.
March 2001	Approval was granted from MIT/Microsoft I-Campus to support the STEFS project.
June 2001	ENVIT Group formed at MIT Core STEFS project team assembled
Summer 2001	Conceptual design of STEFS project.
Sept 2001	STEFS, undergraduates seminar
Oct 2001	M.Eng. project
Oct 19 2001	Detailed design
Nov 30, 2001	Module prototype
Dec 7, 2001	Integration prototype
Dec 14, 2001	Boston/Cambridge (USA) field trial
Jan 14-18, 2002	Williams River, Australia trial and field study
February-May, 2002	Systems enhancements and exploration of other applications

1.7 Overview of Thesis

This thesis is organized by the project modules described in Section 3 of this chapter in order to answer the questions outlined in Section 1.1. Chapter 2 discusses the alternatives, selection, and implementation of the wireless data transmission system between PDAs and the field laptop

server. Chapter 3 discusses the alternatives, selection, and implementation of the wireless data transmission system between the field laptop server and a fixed web server. Chapter 4 discusses the design, implementation, and testing of software systems used to collect, organize, and transmit data in the STEFS system. Chapter 5 discusses the design, implementation and testing of the methods and software for integrating measured data with geospatial coordinates and displaying that data on an electronic map. Chapter 6 compares the system with similar systems on the market and investigates costs of development and of future enhancements and implementations.

1.8 More Information

For more information on the STEFS concept, refer to "Development of mobile computing applications for hydraulics and water quality field studies," Camilli, et all, 2002. For more information on the development of the STEFS project, refer to "EnviroCom Final Report (2002)," Agarwal, et al; "EnviroCom Project Proposal (2001)," Agarwal et al; and "Software Tools For Environmental Field Studies Final Report (2002)," Agarwal et al. Also refer to "EnviroCom Project Proposal Presentation, M.I.T., 2001," Agarwal et al; "EnviroCom Final Presentation, M.I.T., 2002," Agarwal et al; and "EnviroCom Presentation to Environmental Systems Research Institute (ESRI), Inc., Redlands, CA, 2002," Agarwal et al. Finally, refer to the web sites of http://envitweb.mit.edu and http://web.mit.edu/envit/www for the most up to date information on the ENVIT Student Group and STEFS project.

For a detailed look into how the data collected from the STEFS field study in Newcastle, (Australia) was used, refer to "Hydrologic Modeling of the Williams River with tRIBs:

Development and Testing of a Novel User Interface for the TIN-Based Hydrologic Model," Lau, 2002 and "Hydrologic and Water Modeling with HSPF: Utilization of Data from a Novel Field Data Collection System and Historical Archivess," Richards, 2002.

CHAPTER 2: WIRELESS LOCAL AREA NETWORK

2.1 Introduction

This chapter seeks to answer the question of how to transmit data from many handheld computers to a mobile field server. It describes the WLAN (Wireless Local Area Network) used by STEFS to transmit data between Mobile PDAs and a Mobile Field Laptop (as shown in Figure 2.1). Section 2.2 describes the motivation for having wireless transmission. Section 2.3 describes some of the alternatives available for this type of data transmission. Section 2.4 explains why 802.11b was selected. Section 2.5 explains the complexities of implementing 802.11b into this system and the use of IrDa (Infra Red Data Association) in allowing field teams to transmit their data from remote locations. Sections 2.5 and 2.6 describe the field testing of this module and Section 2.7 describes the revisions to this module as a result of the field testing.

Figure 2.1: Data Transmission between Mobile PDAs and Laptop

Before this author joined the STEFS project, there had been a number of technological choices that had been made and were not subject to change. This chapter and this thesis assume that these choices are design constraints, and alternatives will not be explored in this thesis. Some of these constraints include choosing Compaq (http://www.compaq.com) iPaqs running Microsoft PocketPC Operating System as the PDAs for the STEFS system and the platform for design on the PocketPC to be Embedded Visual Basic (eVB). Throughout this Chapter, we then assume

that iPaq with PocketPC running an Embedded Visual Basic Application is a fixed criterion in the selection of other components in the wireless system. For more information on 802.11b refer to "GPS and Wireless Presentation, M.I.T., 2001," Spieler, Russell.

2.2 Motivation

The wireless data collection system module of STEFS is designed to allow data to pass from the handheld PocketPC to the field laptop, where it is processed for distribution back to the other PocketPCs as well as to web servers for publishing on the Internet. Goals considered for the data collection module are:

- Seamless integration with an Embedded Visual Basic Application running on a PocketPC;
- The ability for multiple PocketPCs to transmit information simultaneously;
- A form factor that matches the handheld nature of the PocketPC
- A system compatible with the PocketPC and the iPaq 3670;
- The ability to transmit data over multiple miles from the mobile PocketPCs to a centrally located laptop;
- A mobile form factor for the central data collection station;
- A central data collection station compatible with a Windows laptop;
- Low cost hardware;
- Low costs of data transmission;
- High rates of data transfer; and
- Low power consumption

2.3 Alternatives

To achieve the goals outlined above, four main options could have been considered. There may exist other options that the author was not aware of, but to the best of his knowledge, they were the options available at the time of development. Table 2.1 gives a comparison of the different options and numeric justifications for assumptions on pricing and range made in this section. The options considered are:

1. Bluetooth technology: This is a rapidly developing wireless data technology that is actually being integrated directly into newer iPaq models such as the iPaq 3870. It is the cheapest option with the most integrated form factor at both the PocketPC (being directly integrated into the iPaq unit) and the laptop (in the form of a PCMCIA card). Its drawbacks are the short range over which data can be transmitted, and the speed at which data can be transmitted.
2. 802.11b technology: This technology has been greatly developed for use with mobile computers and PocketPCs. Its form factor, while not directly integrated into the iPaq unit, can be easily integrated with the unit through a PCMCIA expansion pack. The system is relatively more expensive than other options, but is well supported by the manufacturers. Data transmission rates are faster than most other options at around 11Mbps. Data transmission can occur over a longer range (up to 16 miles under ideal conditions) than most other options when antennas and amplifiers are employed.
3. Radio-based technology: It is not as easily integrated into the PocketPC as the other technologies investigated. No off-the-shelf hardware is suited to interact directly with the PocketPC. Benefits of a radio-based system include longer range than most other systems (up to thousands of miles). Form factors on the PocketPC end are likely to be

unacceptably large, and data transmission rates are unacceptably small (about 4200bps). While initial hardware costs might be lower than other systems, time and effort in modifying and maintaining the system would likely cancel out the cost advantages of this technology.

4. Cellular technologies: These technologies, especially Cellular Digital Packet Data (CDPD), have extensive networks, readily available hardware that can integrate with PocketPC, and plenty of customer support to ensure success. Unfortunately data rates are not cost effective and transmissions are still relatively slow at 19200bps. In addition, coverage areas in remote environmental data collection sites can be quite poor, if existent at all.

2.4 Selection

Feature	Bluetooth	802.11b	Radio	Cellular
Embedded Visual Basic Integration	Easy	Easy	Hardware Adaptation	Software Adaptation
Simultaneous Transmission	Up to 10	Infinite	Only One	Only One
Form Factor for PocketPC	Integrated	PCMCIA Expansion	External Cable	External Cable
PocketPC iPaq Compatibility	Yes	Yes	Not Easily	Yes
Range	10 meters	Up to 16 miles (amplified)	Up to thousands of miles	Limited by Coverage
Form Factor for Laptop	PCMCIA	External Antenna + Router	External Antenna + Transmitter	PCMCIA
Windows Laptop Compatibility	Yes	Yes	Not Easily	Yes
Hardware Cost (3 units)	$400	$2,000	$1,000	$2,000
Transmission Costs	0	0	0	Relatively High
Speed	1Mbit/sec	10Mbit/sec	56kbits/sec	19kbits/sec
Energy Consumption	Very Low	Low	Very High	Low

Table 2.1: Wireless Technologies Features Comparison Chart

The 802.11b system was chosen primarily for its large range, fast data transmission rate, small form factor, and relative ease of integration into an Embedded Visual Basic Application running on a Compaq iPaq PocketPC (http://www.compaq.com). The Orinoco (http://www.orinocowireless.com) COR-1100 Router and the Orinoco Silver PCMCIA Cards provided the necessary capabilities in an affordably priced system (see APPENDIX Wireless Funding Proposal) for around $2000. With the addition of a high-gain 15dB omni-directional antenna and a 1-watt amplifier, the system has a theoretical range of around 16 miles.

2.5 Implementation

In order to implement the selected Wireless Wide Local Network (WLAN), each iPaq must have a PCMCIA expansion pack with an Orinoco Silver 802.11b wireless PCMCIA card. In addition the field laptop must be connected to an Orinoco COR-1100 via crossover Ethernet cabling. In order to achieve the 16-mile range, the Orinoco COR-1100 is connected to a high-gain antenna through an amplifier. The system communicates over TCP/IP. The laptop is the server in the system, and is given the IP Address 10.0.0.1. The Orinoco COR-1100 is the gateway in the system, and is given the IP Address 10.0.0.2. Each iPaq is given an IP Address in the range of the server and gateway 10.0.0.X. Each iPaq is initialized to use the server and gateway. The iPaqs use Orinoco Client Software to maintain their connection to the system while the laptop uses Orinoco Router Manager Software. The actual data transmission is done by the Embedded Visual Basic Application, which is described in Chapter 4 of this thesis.

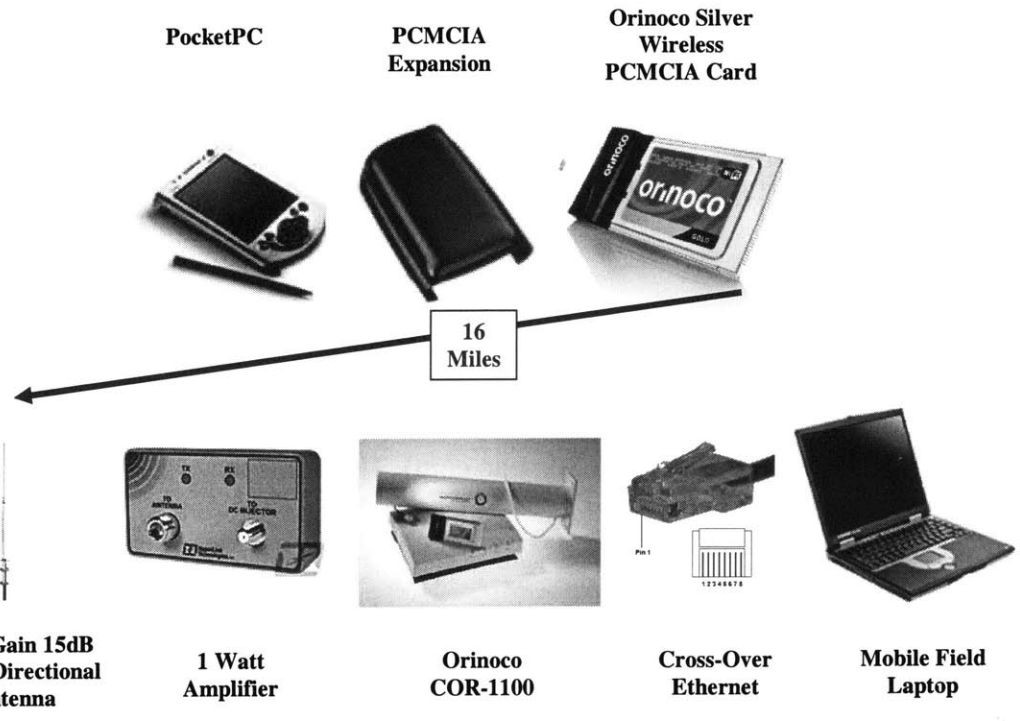


Figure 2.2: 802.11b Implementation Diagram

2.6 PDA Teams and iRDA Integration

Unfortunately, form factor issues prevented the use of both the GPS and 802.11b PCMCIA cards in the same unit. While Compaq (http://www.compaq.com) does sell a "Dual Expansion Pack" capable of integrating two PCMCIA cards with the iPaq, the Teletype (http://www.teletype.com) GPS PCMCIA card does not physically fit with the Orinoco (http://www.orinocowireless.com) Silver 802.11b PCMCIA card. This is because both cards have a bulky external piece. No 802.11b cards that could fit with the GPS card, and are compatible with the iPaq were being manufactured at the time of the design. As a result, it was necessary to implement a two iPaq team system.

As shown in Figure 2.3, iPaq one is equipped with a Teletype GPS PCMCIA card via the expansion pack, and a Hydrolab (http://www.hydrolab.com) Water Quality Sensor via the RS-232 port. This data is all entered into the system automatically via the Embedded Visual Basic application. Because iPaq does not have a wireless card, it must travel with a second iPaq equipped with a wireless card. It will pass its data via the iRDA port (standard on the iPaq) to iPaq two. This second iPaq, which is equipped with a wireless card, sends its own data (entered through the Embedded Visual Basic application's Graphical User Interface) as well as iPaq one's data over the 802.11b to the field laptop (see Figure 2.4). As a result, any data on iPaq two will need to be associated with the geospatial data collected by iPaq one. This will be discussed in Chapter 5 of this thesis in more detail. The over all three-team system is illustrated in Figure 2.5. For information on this three-team system refer to "Field Data Streaming Presentation. M.I.T., 2002," Vivioni.

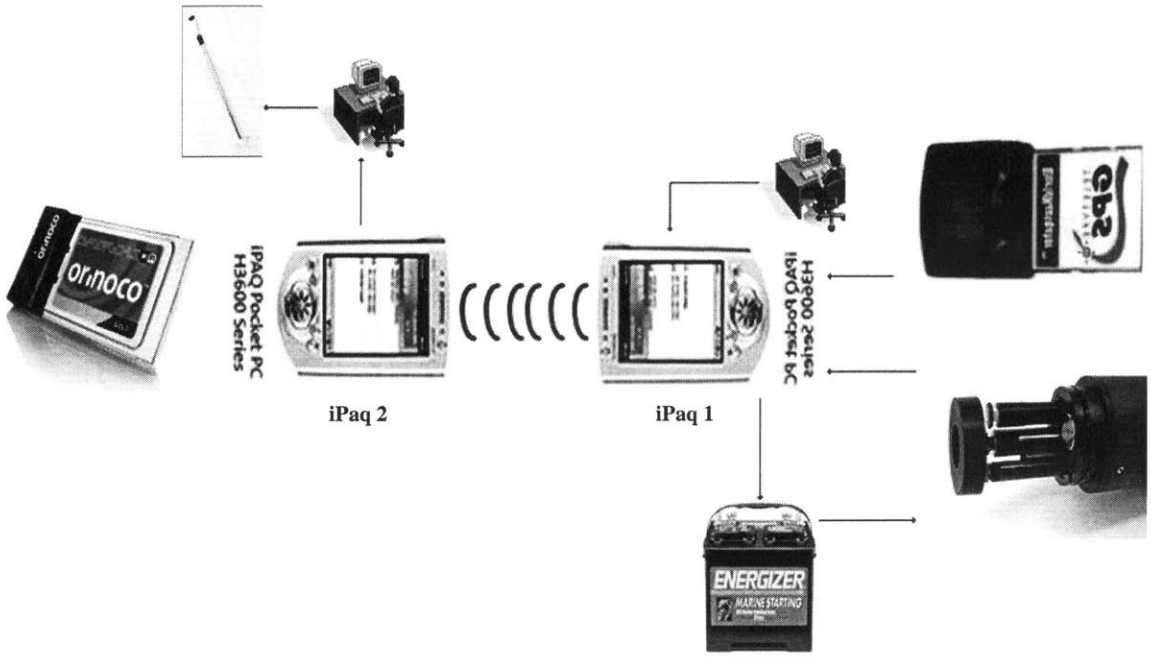


Figure 2.3: iRDa Data Entry and Transmission Set-up

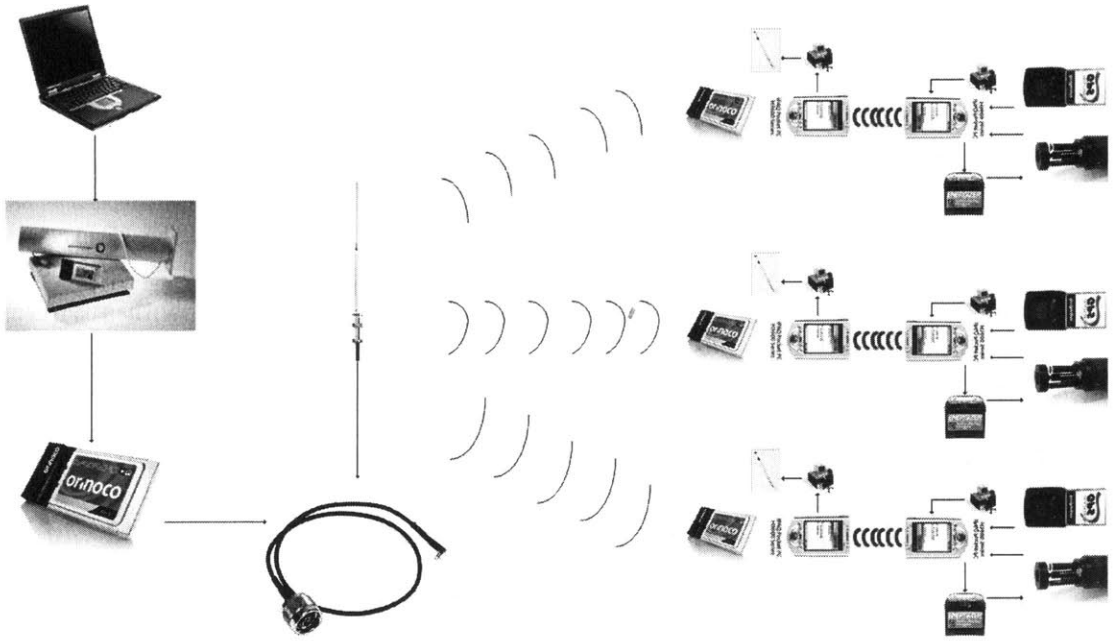


Figure 2.4: 3 Team 802.11b Data Transmission with iRDa Data Entry and Transmission Set-Up

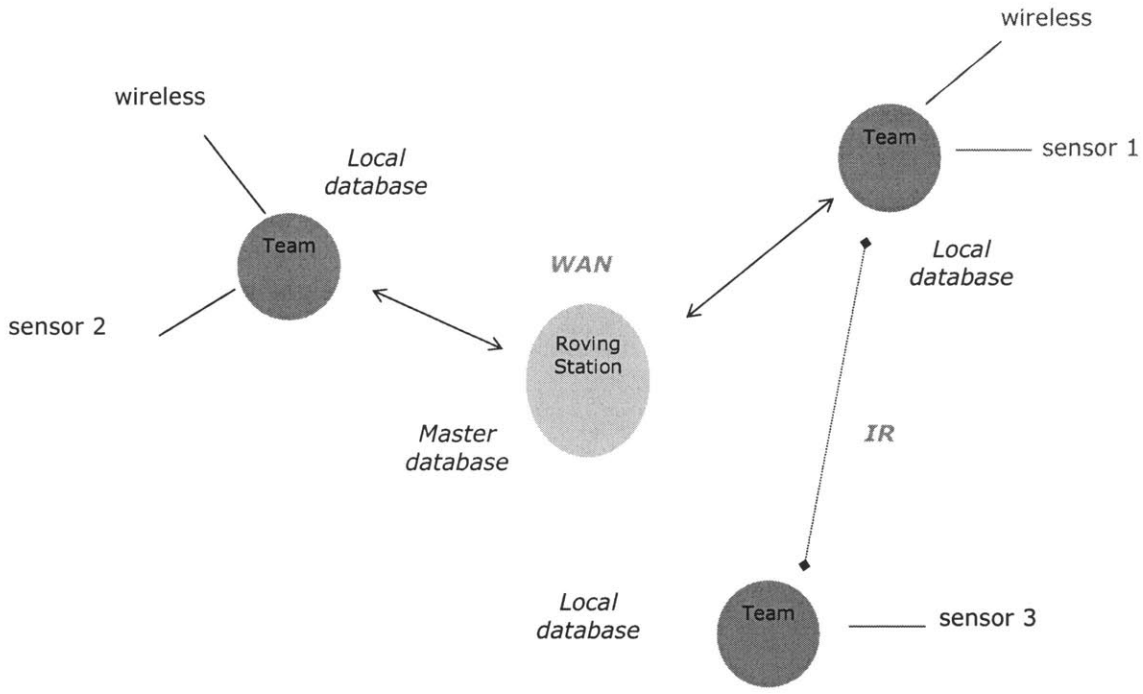


Figure 2.5: 802.11b and iRDa Data Entry and Wireless Transmission Schema
Courtesy of E. Vivoni, pers. comm., 2002

2.7 Cambridge Field Test

On December 14th, 2002, three months after the start of development on the system, a field test was run in Cambridge and Boston, MA, USA. As shown in Figure 2.6, teams were deployed in Cambridge and Boston to take measurements in the Charles River along side MIT. Each team had a PocketPC equipped with the 802.11b PCMCIA cards. The 802.11b Wireless Router and Laptop were positioned in a field van a few hundred feet from the Cambridge team (shown in Figure 2.7). During this field test the laptop was constantly pinging both PocketPCs in order to determine whether or not they were within communication range. This test showed partial success for the 802.11b wireless System. The PocketPC in Cambridge was within communication range throughout the entire field test. The PocketPC in Boston was not within range for most of the field test. This was

mainly due to a building that was directly obstructing the line of sight between the wireless router antenna and the Boston Team. When the Boston Team moved slightly west of their data collection site and established a line of sight, they were within clear communication range. The distance from the wireless router to the Boston Team was almost .75 mile. From this test, it was clear that the line of sight was needed for the success of the system.

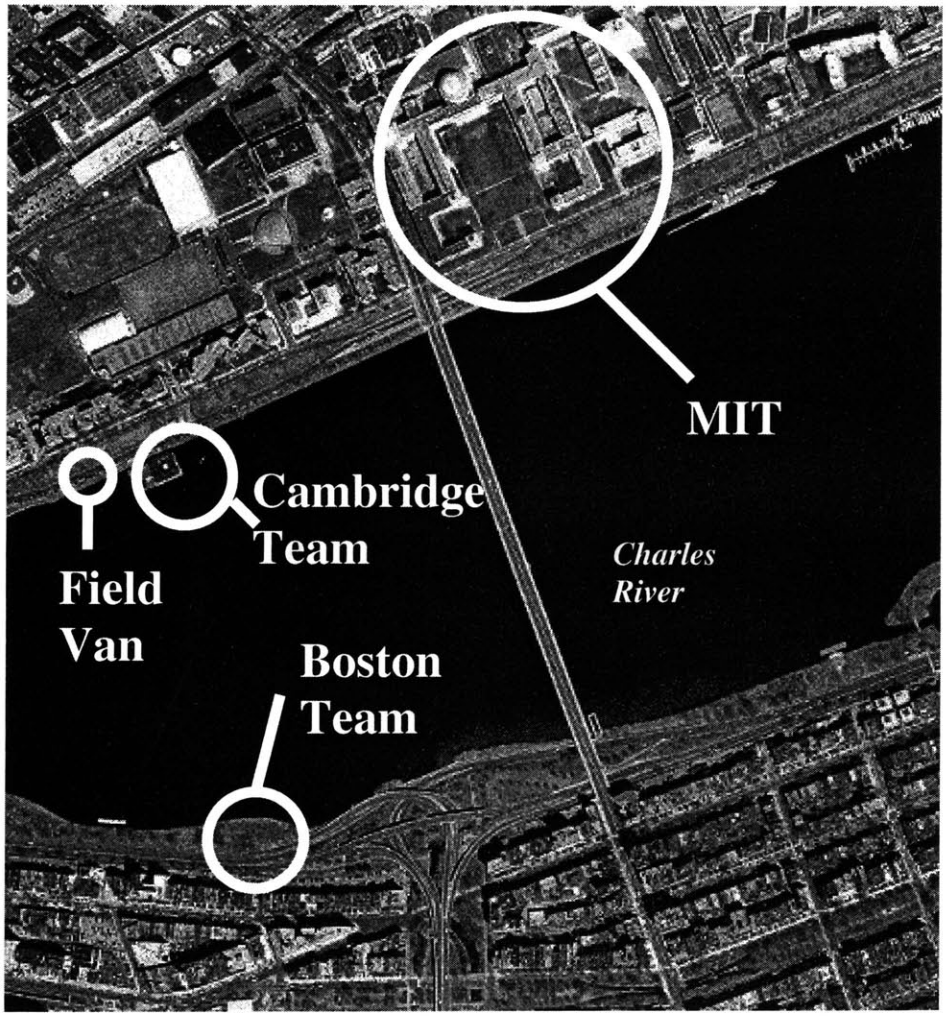


Figure 2.6: Cambridge Field Test Map

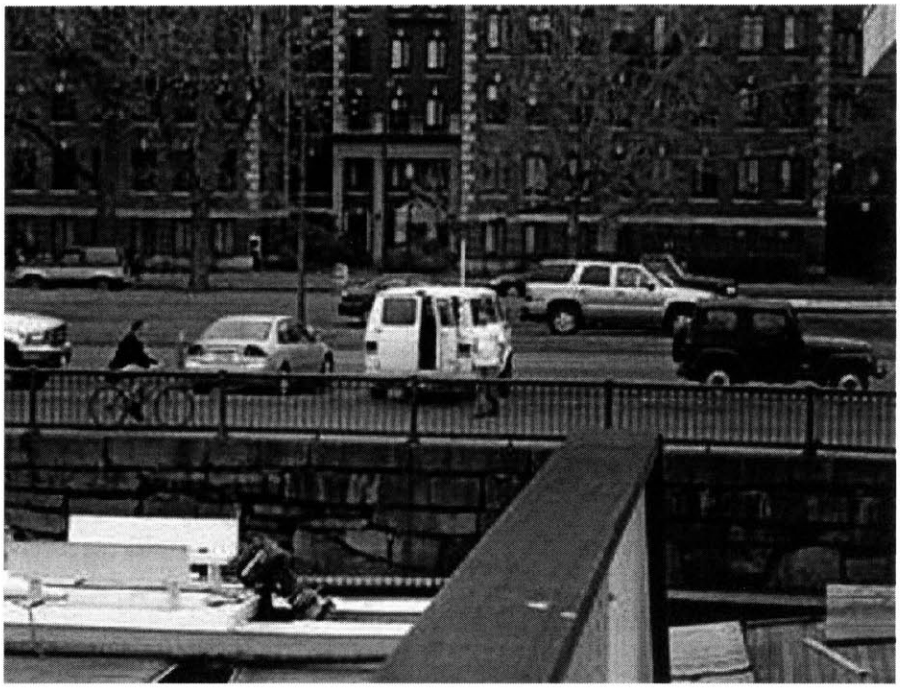


Figure 2.7: Field Van with 802.11b Router and Antenna During Cambridge Field Test

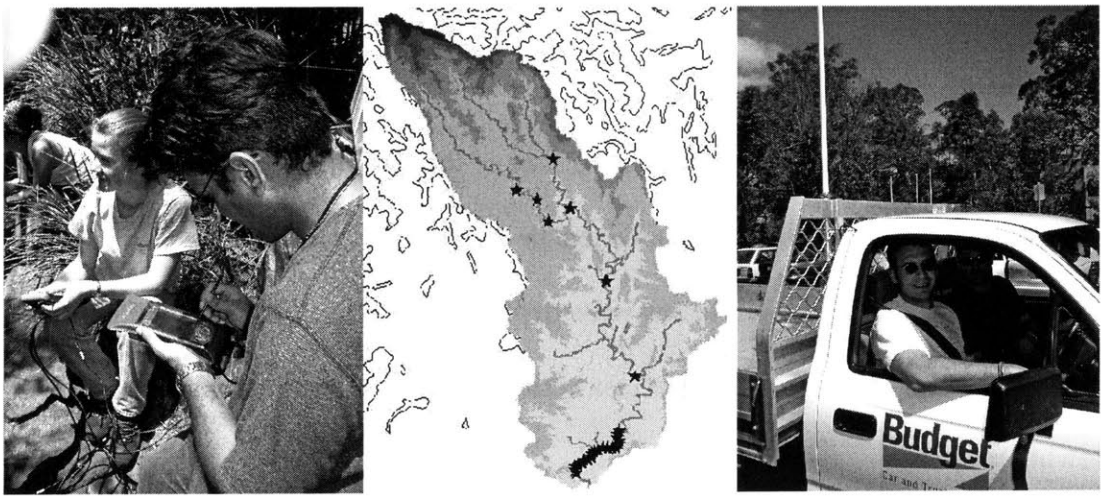
2.8 Newcastle, Australia Field Test

On January 16th, 2002, six months after the start of the development of the system, a full scale data collection effort was conducted in Newcastle, Australia using the system. During a three-day study, three teams were deployed over the 1100 km^2 Williams River watershed (see Figure 2.8 b). The wireless system was not as successful as desired for the following reasons.

The terrain was uneven and the river was in a valley. As a result, line-of-sight was not achieved at most data collection sites. The plan was to drive the Field Van to high points in order to improve line of sight. Time and fences indicating private property did not allow for the van to travel very far to look for higher positions. As a result, the maximum distance over which the wireless system achieved data transmission was only .75 mile.

To collect data from all groups, the van was required to drive from site to site, collecting data as we drove by (see Figure 2.8 c).

In addition to testing the 802.11b wireless system, the Australia field test was the first time the iRDa system was tested. It was also found to be substandard for many reasons. Primarily, the transfer of data over iRDa required the user to exit out of the Embedded Visual Basic application and go through some rather not intuitive steps to transmit data. This resulted not only in a lot wasted of time and effort by the field researchers, but also in a high risk for loss of data. A secondary issue was ambient light and the protective pouch, shown in Figure 2.8 a, obstructing the iRDa data transfers.



(a) **(b)** **(c)**

Figure 2.8: **(a)** An 802.11b Equipped PocketPC Sending Data
(b) The 1100 km^2 Williams River Watershed in Newcastle, Australia
(c) The Roving Field Van Equipped with 802.11b Router, 15dB High-Gain Antenna, and 1 Watt Amplifier

2.9 Enhancements

As mentioned above, the primary shortcoming of the wireless system was the use of iRDa. As a result, it was desirable to remove iRDa from the system. In order to do this, it was necessary to incorporate both the GPS PCMCIA sensor and the 802.11b wireless PCMCIA cards into the same PocketPC. This was previously impossible because both PCMCIA cards had a bulge on their external end, making it impossible for them to fit into the Dual-PCMCIA expansion pack together. Fortunately, Compaq (http://www.compaq.com) now makes a "slim" 802.11b PCMCIA card, that does not have a bulge on their external end. Using this card, both GPS and Wireless can be incorporated into a single PocketPC eliminating the need for iRDa as well as the need for two PocketPCs in a team.

CHAPTER 3: GLOBAL WIRELESS NETWORKS

3.1 Introduction

This chapter seeks to answer how to transmit data from the field server to a fixed web server thousands of miles away. It describes the Global Wireless Networks used by STEFS to transmit data between a Mobile Field Laptop and a Fixed Web Server (shown in Figure 3.1). It will describe the motivation for having global wireless transmission, some of the alternatives available for this type of data transmission, why General Packet Radio Service (GPRS) was selected. It will also explain the complexities of implementing GPRS into this system. Finally, it will describe how this module performed during field testing.

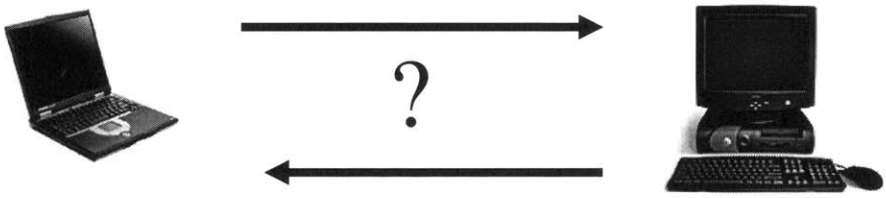


Figure 3.1: Data Transmission between Mobile Laptop and a Fixed Web Server

3.2 Motivation

The wireless data distribution module of STEFS is designed to allow processed data to pass from the mobile field laptop to the fixed web server for publishing on the Internet. Goals considered for this module are:

- The ability to transmit data up to thousands of miles;
- A mobile form factor for the mobile field laptop
- The ability to transmit data from anywhere in the world;
- Low costs of hardware;

- Low costs of data transmission;
- High rates for data transfer;
- Low power consumption; and
- The ability to automate the transmissions using the Windows operating system.

3.3 Alternatives

To achieve the goals mentioned above, three options were considered. There may exist other options that the author was not aware of, but to the best of his knowledge, there were the options available at the time of development. Refer to Table 3.1 for a comparison of the different options and numeric justifications for assumptions on pricing and coverage made in this section. The options considered were:

1. GlobalStar Satellite Phone technology: It allows for coverage from anywhere on the globe. This allows the STEFS system to operate from any area during an environmental field study, including remote and isolated areas. The costs of hardware and data transmission can, however, be relatively high.
2. Global System for Mobile Communications (GSM) technology: This technology has been around in Europe for more than a decade, where it has nearly ubiquitous coverage. While it is relatively new to the US and where it has primarily urban coverage, it is becoming the international standard for wireless phones. GSM makes use of SIMM cards which carry the identification for a specific account on a specific network. With the use of these SIMM cards, the same phone can be used on one network in the US and another network in a foreign country, by switching the SIMM card.

3. GPRS technology: This is an extension of the GSM technology. GPRS phones have all the features of GSM only phones, with additional benefits. GPRS allows direct connection to the internet with out dialing out to a server. Compared to GSM, GPRS offers much faster data rates and charges per kilobyte (as opposed to per minute). Its coverage areas are currently less extensive than GSM. Because all GPRS phones have GSM capability, if the phone is outside of GPRS coverage, it can still transmit data over GSM.

3.4 Selection

All three options are almost identical in their ability to transmit data across the world over a global network and both use a mobile telephone for hardware. Table 3.1 summarizes the attributes of each alternative for the goals for this module.

Feature	Satellite	GSM	GPRS
Coverage Area in the Globe	100%	Primarily Urban	Less than GSM
Hardware and Basic Service Costs	$1,624	$500	$1,096.90
Included with Basic Service	50 mins / month	500 mins / month	10 MB / month
Costs for Use Over Included Service	$1.39 / min	$.30 / min	$4.00 / MB
Use Costs Outside US	$2.39 / min	$.44 / min	$10.00 / MB
Data Rate	19.2 Kbps	9.6 Kbps	64 Kbps
Windows Laptop Compatibility	Dial out Modem Is Cumbersome	Dial out Modem is Cumbersome	GPRS Direct Connection to the Internet

Table 3.1: Longer Range Wireless Technologies Features Comparison Chart

GPRS was chosen primarily because the system is significantly less expensive for both the hardware and the service, the data rates are significantly faster, and the feature of GPRS to directly connect to the internet as opposed to having to dialup to the fixed web server to transmit data. While the limited coverage area was of concern, both the Voice Stream (http://www.voicestream.com) network available in Boston (where the system would be developed) and the Telstra (http://www.telstra.com) network in Australia (where the system would be field tested) had coverage areas that appeared would be sufficient for the systems needs. Total proposed cost, is about $1100 (see APPENDIX Wireless Funding Proposal).

3.4 Implementation

The Motorola (http://www.motorola.com) P280 is a GSM/GPRS phone. It uses a frequency of 900 / 1800 MHz when on networks in Europe and Australia, and a frequency of 1900MHz when on networks in the US. The P280 connects to the laptop using a USB data connectivity kit and software provided by the carrier. The phone can connect the laptop to the Internet giving it a temporary IP Address on the GPRS network. Theoretically, because billing is per kilobyte and not per minute, the phone should be connected during the entire field study. The Mobile Field Laptop has a mapped network drive on the Fixed Web Server, which is activated when the GPRS phone is connected. VoiceStream was used as the carrier in Boston and Telstra was used as the carrier in Australia. Once the data travels across these networks to the Internet, the Web Server, which is connected to MIT Ethernet, stores the data. The data is then available upon request from the outside world. The web services site provides up-to-date images upon requests, based on the live data. Figure 3.2 shows how the hardware in this module connects to transmit data from the field to the fixed web server at MIT.

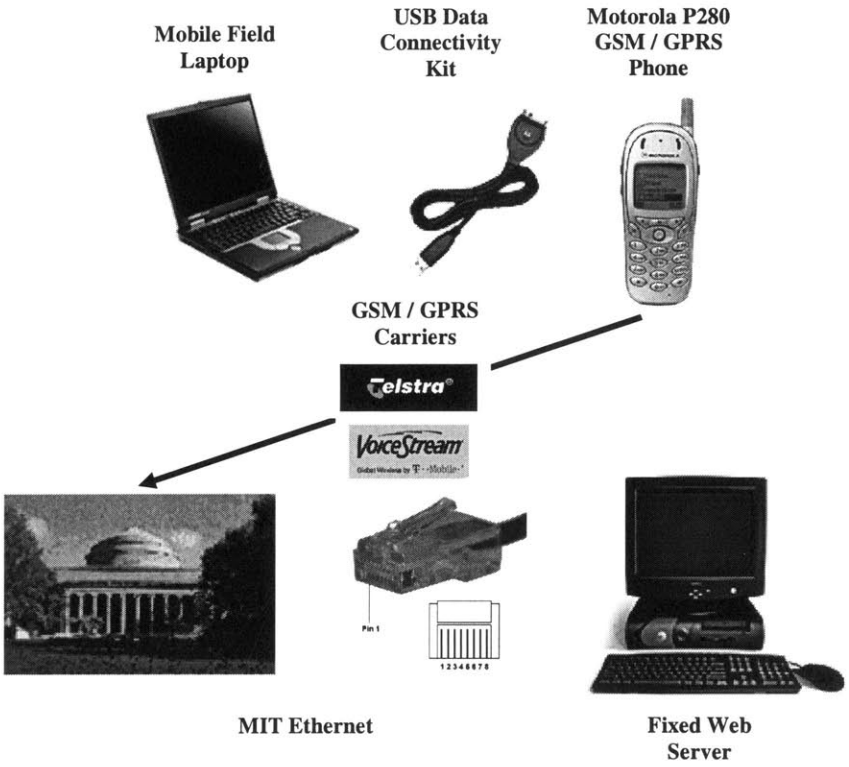


Figure 3.2: GPRS Implementation Diagram

3.5 Cambridge Field Test

The Cambridge Test only allowed for one test of the GPRS Data transmission system. This test was successful as was expected, as the system was in a major metropolitan area. This area was the same area where we designed the system. Hence, it was unlikely that any problems that had not previously been encountered in the lab, would occur.

3.6 Newcastle, Australia Field Test

The Newcastle Test was significantly alerted due to time constraints. The Phone needed a software upgrade to use Telstra's GPRS system in Australia. Unfortunately that upgrade could only be completed in Sydney, Australia about three hours drive away from Newcastle. Without the software upgrade, the only way data could be transmitted back to the Web Server was using

the GSM voice capabilities of the phone, a regular modem, and MIT's Dial-Up Internet Service Provider Tether. The results were significantly slower data transmissions at extremely higher cost. To complete updates of the Web Server took hours instead of minutes and cost hundreds of dollars for the trip as opposed $50-$100.

In addition, the coverage in the remote areas where the field testing was being conducted was quite poor. The phone received GSM coverage at roughly 20% of the field sites. This suggests that a more ubiquitous system such as Satellite Phone might be necessary for use in remote areas.

CHAPTER 4: DATA COLLECTION, MAINTENANCE, and DISTRIBUTION

4.1 Introduction

This Chapter explores what software and data structures are required for this type of data distribution. It describes how a relational distributed database is updated locally on PocketPCs and integrated on a mobile laptop computer. The chapter describes the methods used by STEFS to collect, maintain, and distribute data. Section 4.2 explains how the database was originally developed. Section 4.3 describes the early revisions to the database. Section 4.4 discusses how the database integrated all of the other modules of the project. Section 4.5 describes the finalized database. Section 4.6 describes how the database is pre-configured using a Windows Visual Basic .NET Application. Section 4.7 explains how that pre-configured database is used by an Embedded Visual Basic Application on the PocketPC to enter field data. Section 4.8 describes how that Embedded Visual Basic Application uses the 802.11b wireless system to transmit data from the PocketPC's local database to the master database on the Field Laptop. Sections 4.9 and 4.10 address the field testing of this module and Sections 4.11, 4.12, and 4.13 discuss the revisions and conclusions that resulted from that testing.

As explained in Chapter 2, before this author joined the STEFS project, there had been a number of technological choices that had been made and were not subject to change. This chapter and this thesis assume these choices are design constraints that will not be explored in this thesis. Throughout this chapter, we then assume that iPaq with PocketPC running an Embedded Visual Basic Application is a fixed criterion in the selection of other components in the wireless system.

This chapter and the software it discusses could not have been written without guidance from references. Please refer to Reference 10 for assistance in programming in C#.NET; References 13 and 14 for assistance in programming Visual Basic; Reference 8 for assistance in programming in SQL Server and SQL Server CE; Reference 11 for assistance in programming Microsoft Access; and References 7, 12, 17, 18, and 20 for assistance in programming in Embedded Visual Basic and other programming for Windows CE devices. Also refer to http://msdn.microsoft.com and http://www.microsoft.com for assistance in coding for the Microsoft .NET platform and for PocketPC.

4.2 Development

The STEFS database was designed to allow multiple sensors on multiple PocketPCs to record data such that the roving field laptop could collect and process that data. The goal was for the laptop to easily produce an output table of GIS data. This data should be readable by display media including Geographic Information Systems (GIS) web services over the Internet, an Environmental Studies Research Institute (ESRI) ArcIMS server over the Internet, and ESRI ArcPad back on the PocketPC (see Chapter 5). Goals considered in design of this module are:

- The Embedded Visual Basic Application should automatically record spatial data from the GPS sensor;
- The Embedded Visual Basic Application should automatically record water quality data from the Hydrolab sensor;
- The Embedded Visual Basic Application should record data entered manually into the PocketPC;

- The Embedded Visual Basic Application should record data for a cross section of a river as well as for an individual point in that cross section;
- The Embedded Visual Basic Application should should record and store all data collected;
- The STEFS system should filter out or average data to aggregate the most useful data collected for use in the GIS output table;
- The STEFS system should associate all data with the site it was collected at, the date and time it was collected, the equipment it was collected with, the person who collected it, and the PocketPC it was recorded on;
- The STEFS system should associate a specific GPS location with each data collection site;
- The Embedded Visual Basic Application should validate data to ensure that it is within a specified range for each measurement; and
- The STEFS system should pre-populate the database with all equipment and user information using a Windows Visual Basic .NET Application.

4.3 Early Revisions

Early revisions of the database allowed for collection of data from specified sensors without the intention of integration or display. The database carried no information about the equipment itself and only allowed for the measurements from a specific instrument to be logged and stored for future analysis. While this was useful, it was not robust enough to manage the different data types that STEFS would need to collect.

The system needed to allow the user to track what equipment was used to collect data, who collected it, and where they collected it from. It was also desirable to have a system that could collect data from any equipment, not just the equipment owned by the ENVIT team. This would allow for the system to be expandable to other field studies in the future. Finally, the system needed to have the capability of presenting the data in GIS format, relating the GPS location data to the measurements collected at that location (see Chapter 5). The original database design did not allow for this type of data integration.

4.4 System Integration

There were many different goals in mind while developing the database. The Embedded Visual Basic Application needed to be able to easily read and write equipment choices and login information. It also needed to easily enter measurement data into the database. The GPS needed to be able to automatically enter positional data and the automated instruments (in this case Hydrolab) needed to be able to automatically enter data. The database needed to also be expandable to carry more instruments and measurements easily. Finally, the database needed to be able to convert the data into GIS readable format (see Chapter 5), so that the different GIS displays could easily read the data. Finally, the database needed to be able to show instrument calibrations, validate measurements, and keep track of who entered data and with what equipment. The resulting system was relatively complex.

4.5 Database Finalization

The database in its entirety can be seen in Figure 4.1. It was determined that there were eight distinguishable data categories that would be entered into the system. These are: Data about the

equipment being used, data about the log-in, data used for calibration, data used to validate measurements, location data from a GPS sensor, data to be entered by hand from a data collection kit or external sensor, and data to be entered automatically from an attached sensor.

Maintenance of log-in data requires pre-configured user and location information through a Windows application (see Section 4.6). This data can then be retrieved by the log-in form in the PocketPC application and entered into the log-in table when selected through that application (see Figure 4.10 a and b). See Figure 4.2 for the User, Location, and Log-In data tables.

Location data from the GPS sensor, hand-entered data from a data collection kit or external sensor, and data entered automatically are each stored in a separate table. Respectively, GPS Record, Kit Record, and Instrument Record (see Figure 4.3).

All of the data about the equipment, needed to be entered before the data collection effort through a Windows application (see Section 5 of this Chapter). The equipment being used for that particular session could then be selected at log-in (see Figure 4.10 b and c). Therefore, each of the three tables mentioned above has a respective equipment table GPS ID, Kit Type and Kit ID, and Instrument Type and Instrument ID (see Figure 4.4). These tables allow the user to store general data such as make, model, and manufacture date, about all the equipment being used.

Each measurement needs to be validated to be sure the data entered is within the possible values for that measurement. Validation information for each measurement that each of these sensors

and kits is capable of measuring, needs to be entered by the Windows application into the database. The embedded Visual Basic Application can then ensure all data being entered is within the valid range for that measurement by comparing with these values in the database. With this in mind the Kit Measurement and Instrument Measurement tables (see Figure 4.5) were made to check each measurement before it is entered into the Kit Record and Instrument Record tables, to ensure they are valid.

Finally calibration information needs to be entered for certain sensors to ensure that they are taking accurate readings. This information needs to be entered before the use of any sensor requiring such calibration. The Calibration Table is filled in using the Windows application and the Calibration Record table (see Figure 4.6) is validated against it when Calibration is performed in the field using the PocketPC application.

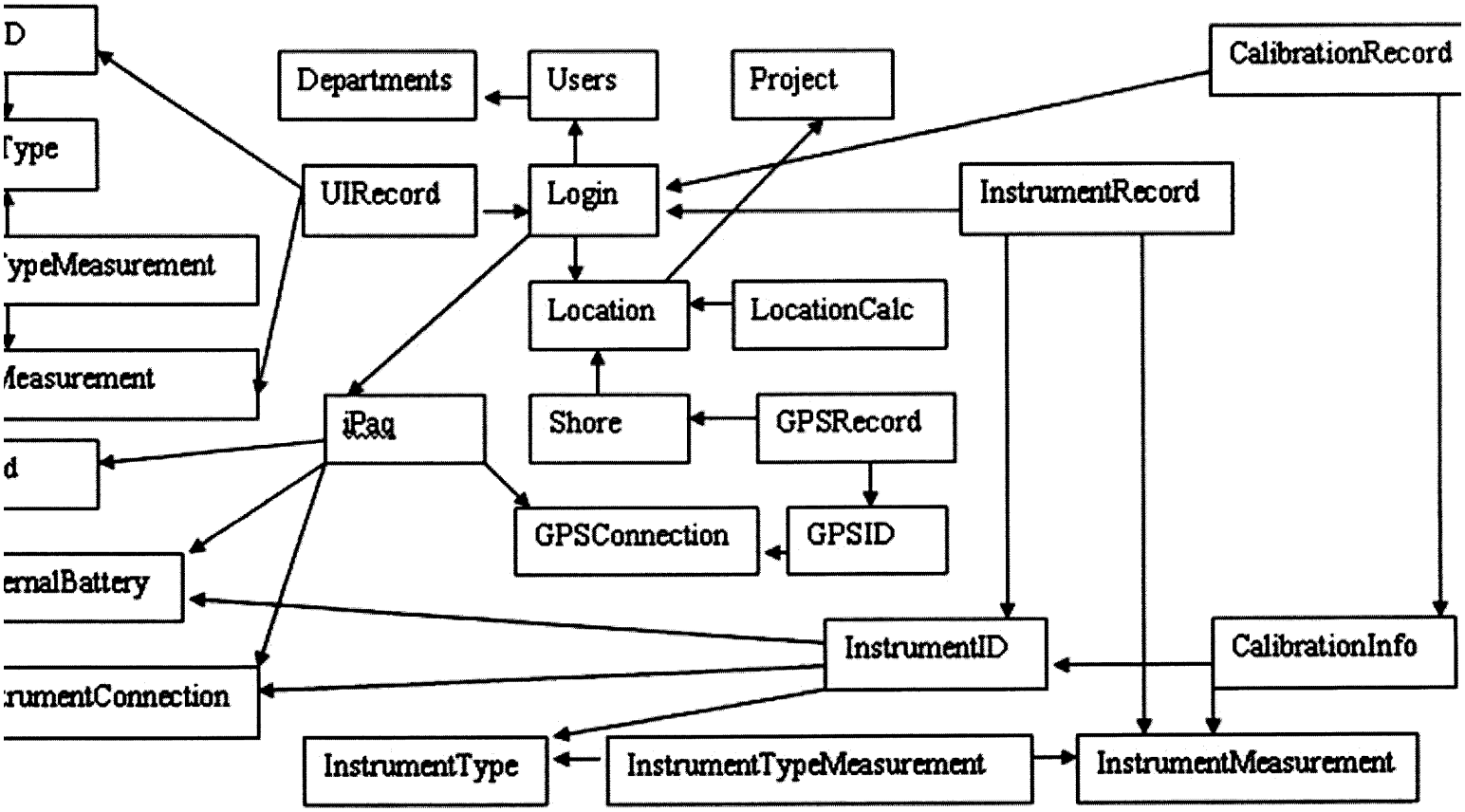


Figure 4.1: Entire STEFS Database

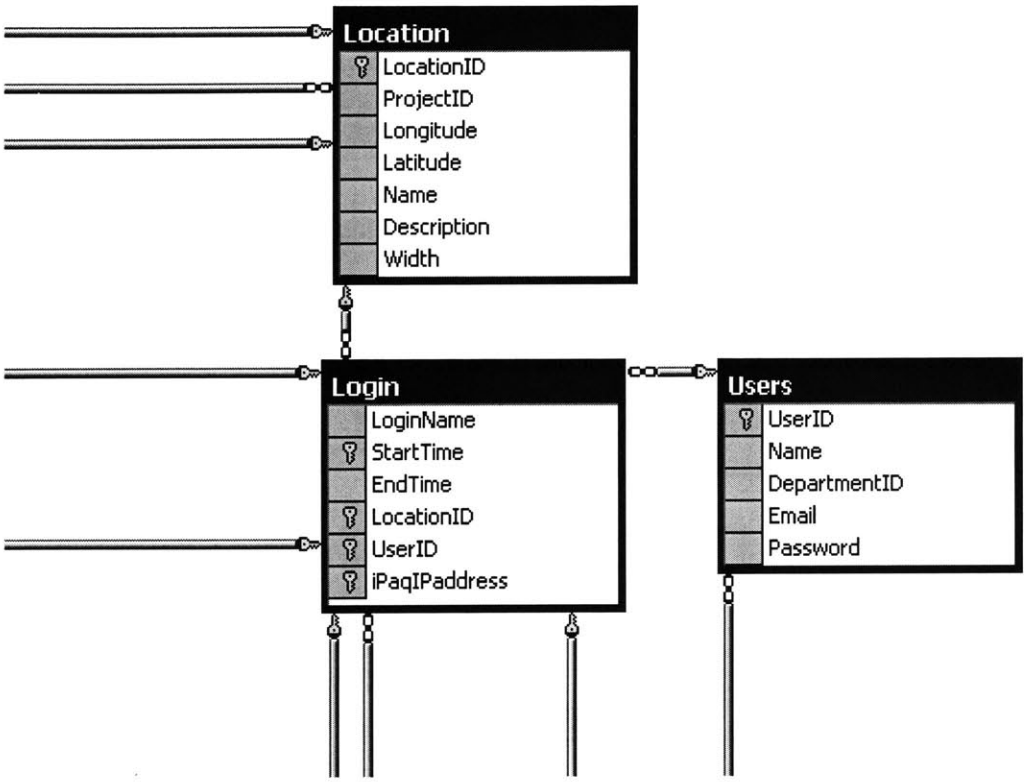


Figure 4.2: User, Location, and Login Tables

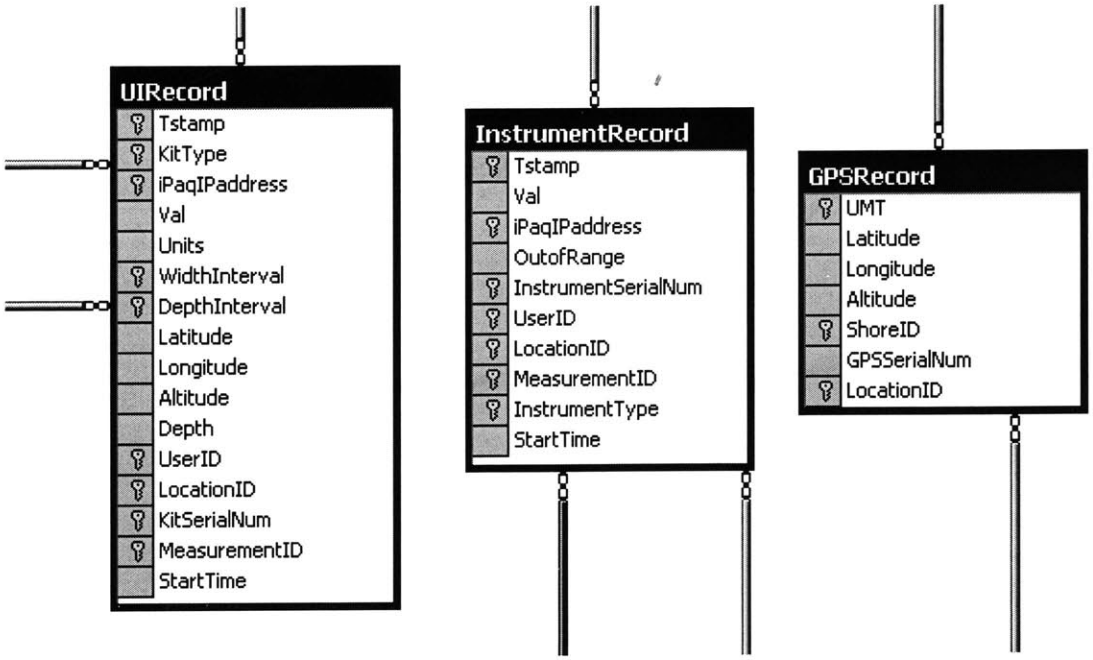


Figure 4.3: GPS Record, UI Record, and Instrument Record Tables

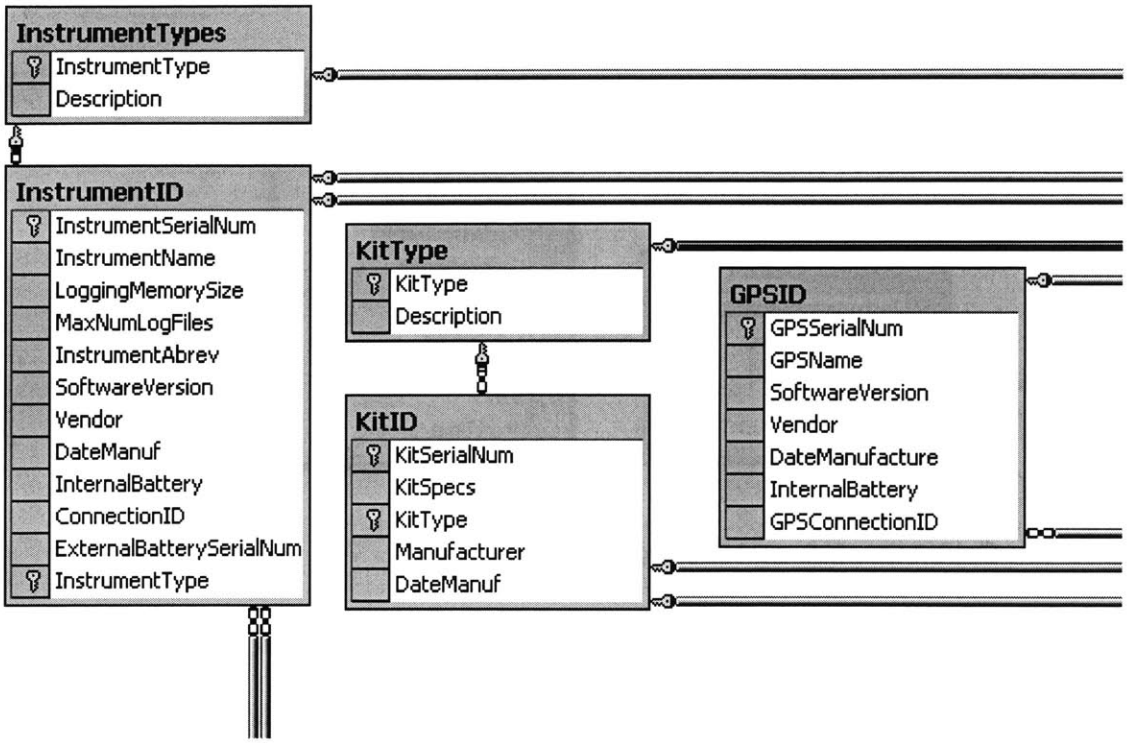


Figure 4.4: GPS ID, Kit Type and Kit ID, and Instrument Type and Instrument ID Tables

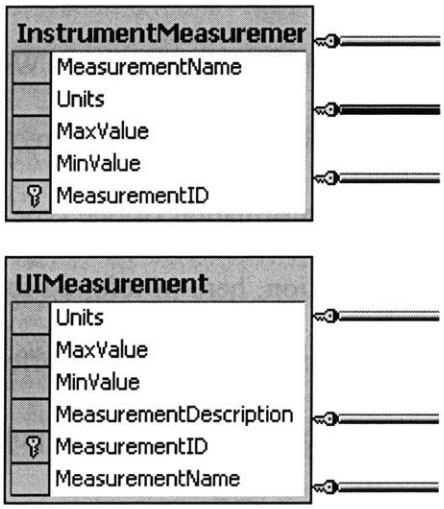


Figure 4.5: Kit Measurement and Instrument Measurement Tables

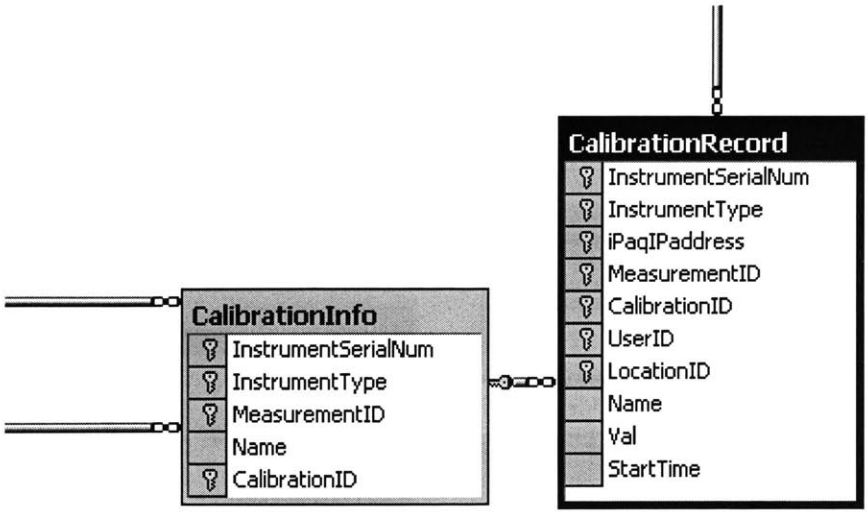


Figure 4.6: Calibration Info and Calibration Record Tables

4.6 Pre-Configuration Through Windows Visual Basic Application

It was necessary to associate all data with the site it was collected at, the date and time it was collected, the equipment it was collected with, the person who collected it, and the PocketPC it was recorded on. In order to maintain this data, the database had to be pre-populated with all equipment and user information. This was accomplished through the creation of a Windows Visual Basic .NET Application, which allows a user to enter this information correctly. By forcing the user to follow a precise set of steps and to enter all information of one type before moving on to the next, the Windows Visual Basic .NET Application, here-in referred to as the ENVIT Configurator Software, ensures that the database integrity is preserved. It effectively transforms the shell of a database, described in Section 4.5 above into a usable populated database which the Embedded Visual Basic Application on the PocketPC can read and write to. The reader is referred to Appendix V of the STEFS Project Report for entire code of ENVIT Configurator.

The ENVIT Configurator Software guides the user through a step by step configuration of the following information: general project information, information about the locations to be visited, the departments of his/her organization, and all users of the system. In addition it prompts the user for statistics about the equipment being used including the: PocketPCs, wireless cards, external batteries, GPS cards, external instruments (sensors) such as the Hydrolab, and independent data collection kits for manual entry into Embedded Visual Basic Application such as a biology or Chemistry kit. Finally, the application allows the user to specify the way that the PocketPC connects to these instruments (sensors). The main menu of these forms is shown in Figure 4.7.

A user manual could be written about the Configurator software, but would be irrelevant to this thesis. As a result, only a few primary screens will be shown here to demonstrate the purpose and use of the STEFS project. Pictured in Figure 4.8 is the general project information form. It allows the user to name a project, gives some information about the purpose and client of the project, indicate relevant dates of the project, and create a bounding box of GPS coordinates where the project occurs. Successful completion of this form will copy the shell database to one with the project name. Already, one can see how information in this form, such as the bounding GPS box, might be used to clip a background map for GIS projections of the collected data.

Pictured in Figure 4.9 is the Kit Measurement form. It is one of the most important forms in the ENVIT Configurator Application. It allows the user to associate measurements with a kit type they just designed. Pictured in Figure 4.9, you can see that the user is editing an existing kit type "Chemistry" and is editing an existing measurement in that kit "Nitrite". The user has the ability

to choose the valid range of values for the measurement as well as the accuracy of this kit in taking this measurement. After using the Configurator, the database should be ready for the PocketPC application to read and select pre-configured users, and equipment. The PocketPC application can associate each measurement to the equipment and user involved with collecting it. It will also validate each measurement to ensure it is in the range of possible values for that measurement type.

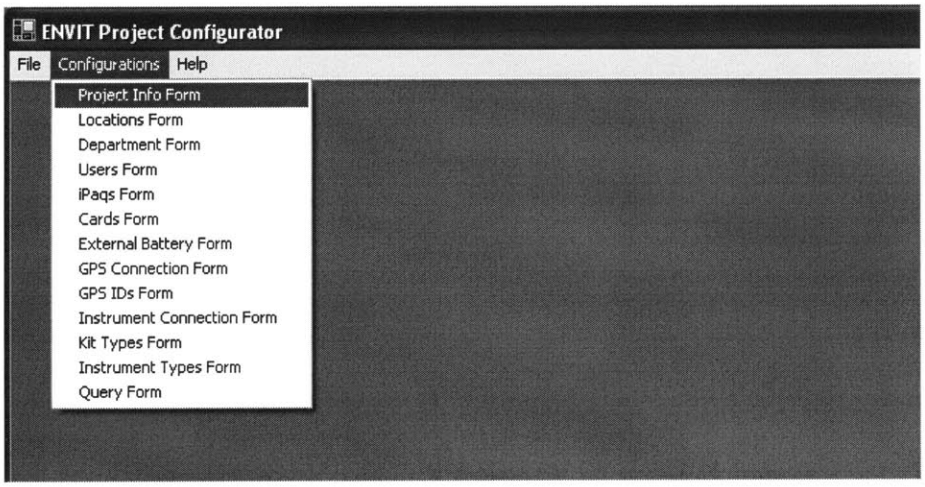


Figure 4.7: ENVIT Configurator Main Menu

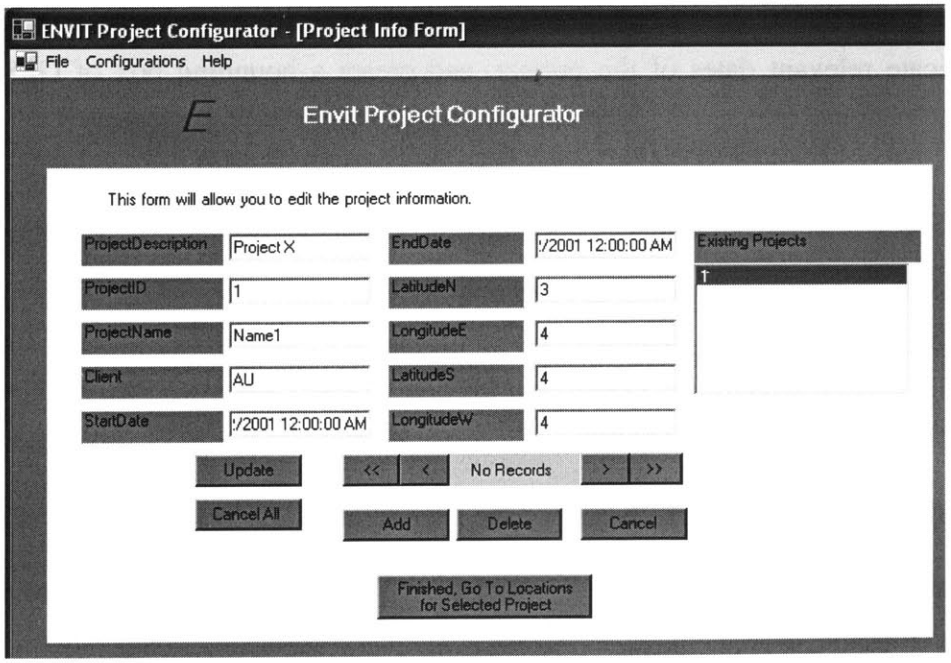


Figure 4.8: ENVIT Configurator General Project Information Form

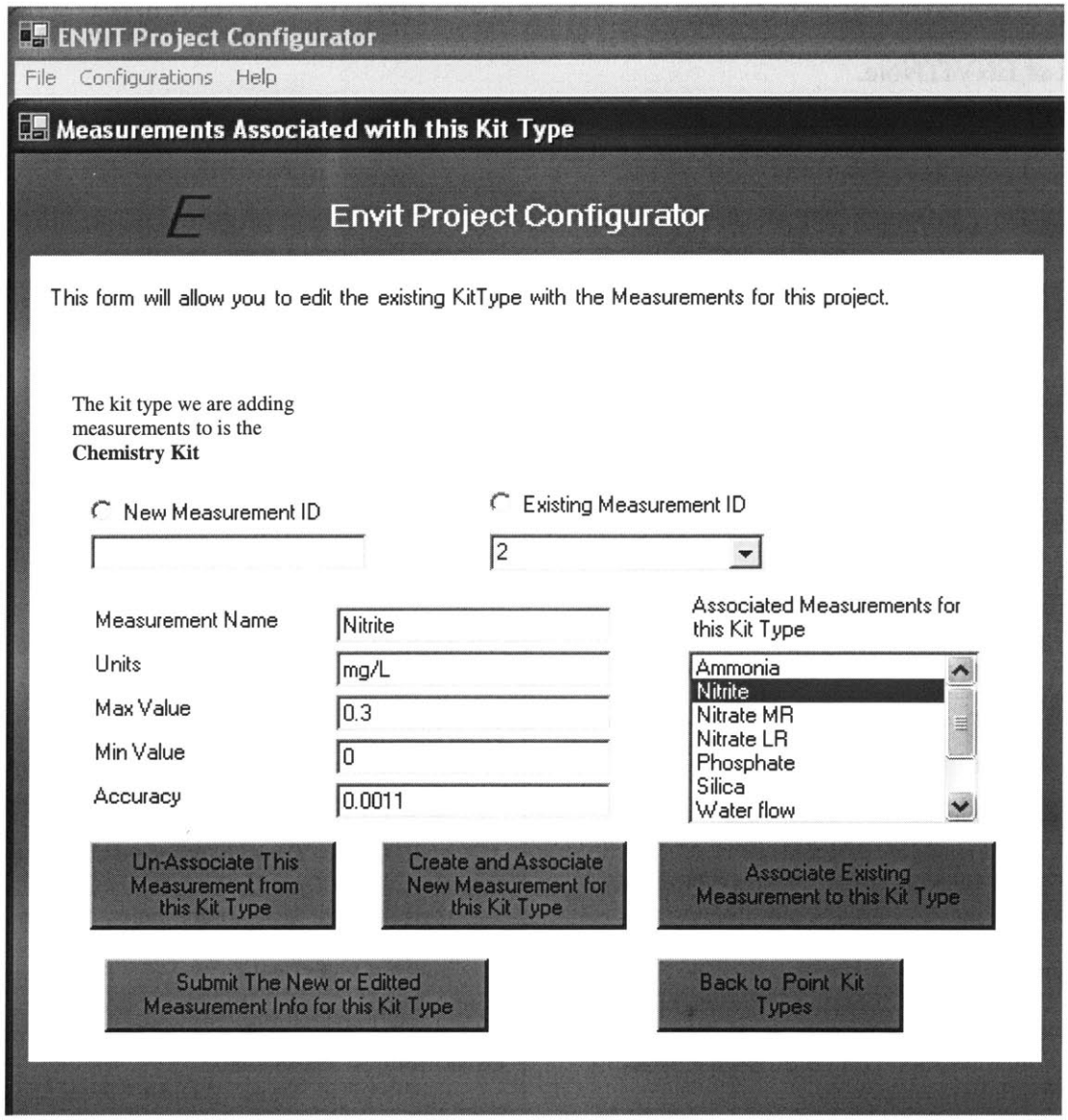


Figure 4.9: ENVIT Configurator Kit Measurement Form

4.7 Data Entry Through PocketPC Embedded Visual Basic Application

Once the database is configured, it needs to be "pulled" (see Section 5 of this Chapter on "pulling" data) onto the PocketPC so that the Embedded Visual Basic Application (here-in referred to as ENVITNote) can read it, allow the user to select equipment and user information on it, and begin entering data into it. The reader is referred to Appendix II of the STEFS Project

Report for entire code of ENVITNote and Appendix VI of the STEFS Project Report for a User Manual of ENVITNote.

To begin the data entry process, the welcome screen of ENVITNote (Figure 4.10 a) allows the user to enter the project (database) name and pull it off the server. Table 4.1 shows the embedded Visual Basic code to "pull" data from a pre-configured database. Section 5 of this chapter provides more information.

```
Private Sub form_activate()
   Dim myDBName As String
   If (welcomeform.txtDatabase.Text <> "") Then
      myDBName = welcomeform.txtDatabase.Text
   Else
      myDBName = welcomeform.DBCombo.Text
   End If

   DBConnection myDBName

   If (isNewDatabase = True) Then
      ' Pull read-only data tables
      myRDA.Pull "users", "Select * From users",
RemoteConn, 0
      myRDA.Pull "iPaq", "Select * From iPaq",
RemoteConn, 0
      myRDA.Pull "Location", "Select * From
Location", RemoteConn, 0
      myRDA.Pull "GPSID", "Select * From
GPSID", RemoteConn, 0
      myRDA.Pull "GPSConnection", "Select *
From GPSConnection", RemoteConn, 0
      myRDA.Pull "InstrumentID", "Select * From
InstrumentID", RemoteConn, 0
      myRDA.Pull "InstrumentConnection", "Select
* From InstrumentConnection", RemoteConn, 0
      myRDA.Pull "KitID", "Select * From KitID",
RemoteConn, 0
      myRDA.Pull "KitType", "Select * From
KitType", RemoteConn, 0
      myRDA.Pull "Card", "Select * From Card",
RemoteConn, 0
      myRDA.Pull "ExternalBattery", "Select *
From ExternalBattery", RemoteConn, 0
      myRDA.Pull "InstrumentTypes", "Select *
From InstrumentTypes", RemoteConn, 0
      ' Pull writable data tables
      myRDA.Pull "InstrumentRecord", "Select *
From InstrumentRecord", RemoteConn, 1
      myRDA.Pull "UIRecord", "Select * From
UIRecord", RemoteConn, 1
      myRDA.Pull "Login", "Select * From Login",
RemoteConn, 1
      myRDA.Pull "GPSRecord", "Select * From
GPSRecord", RemoteConn, 1
      myRDA.Pull "Shore", "Select * From Shore",
RemoteConn, 1
      myRDA.Pull "ENVITOutput", "Select * From
ENVITOutput", RemoteConn, 1
   End If
End Sub
```

Table 4.1: Pull Data From Pre-Configured Database

With the database loaded, the next screen (Figure 4.10 b) allows the user to login to the database with his name, password, which PocketPC he is using, which location site he is studying, and what equipment (and consequently which parts of the application) he will be using. The data to

fill the pull down menus in this form has been pre-loaded by the Configurator tool. The pull down menus are filled with the eVB (Embedded Visual Basic) and SQL (Simple Query Language) code shown in Table 4.2.

```
Private Sub cmbLoc_DropDown()
   On Error Resume Next
   cmbLoc.clear

   Dim myConn As Connection
   Dim myRs As ADOCE.Recordset

   Set myConn =
CreateObject("ADOCE.Connection.3.1")
   myConn.Open LocalConn
Set myRs =
CreateObject("ADOCE.Recordset.3.1")
   myRs.Open "SELECT LocationID FROM
Location", myConn

   Do While Not myRs.EOF
      cmbLoc.AddItem myRs(0).Value
      myRs.MoveNext
   Loop

   myRs.Close
   myConn.Close
End Sub
```

Table 4.2: Fill a Pull Down Menu From Pre-Configured Database

Finally, the user selects the ID numbers of the specific equipment he will be using to collect data at this site and date (Figure 4.10 c). Again, all of this information is made available by the pre-population of the database using the Configurator.

Once the user has logged in and selected all of the equipment s/he is using, s/he can use both automated and manual data entry tools. The automatic data entry tools are displayed above. The Figure 4.11a is the automatic GPS screen. Through the options menu, the user can select a duration and frequency for recording GPS data. By hitting the "Go" button, ENVITNote accesses the GPS unit and begins to search for satellites. Once it finds enough satellites, the screen will indicate which satellites it has found and where in the sky they are relative to the user. Once the GPS has obtained a "fix", it will switch its label in the upper right hand corner from "Awaiting Fix" to "GPS OK". ENVITNote will then begin recording GPS locations at the selected frequency. A timer will indicate the amount of time remaining to record GPS locations.

The user may switch screens and enter data into other screens while the GPS is recording data in the background. Once the timer has run out, ENVITNote will cease recording data and begin averaging the data it just recorded. Table 4.3 contains the embedded Visual Basic Code for automatic GPS data entry.

```
Private Sub Timer2_Timer()

Counter = Counter + 1
If lblStatus.Caption = "SATS OK" Then
EnterGPSRec
'Label6.Caption = Counter


End Sub


Private Sub EnterGPSRec()

   Dim myConn As Connection
   Dim myRs As ADOCE.Recordset
   Dim mySQL1 As String

   Set myConn =
CreateObject("ADOCE.Connection.3.1")
   myConn.Open LocalConn

   Set myRs =
CreateObject("ADOCE.Recordset.3.1")

   'curUMT = lblUTC.Caption
   'curUMT = "01/01/01"

   Dim s1 As String
   Dim s2 As String
   Dim s3 As String
   Dim s4 As String

   On Error Resume Next

   'curlat = CDbl(curlat)
   'curlng = CDbl(curlng)
   'curAlt = CDbl(curAlt)

   'MsgBox "1"
   s1 = "INSERT INTO GPSRecord (UMT, Latitude,
Longitude, Altitude, ShoreID, GPSSerialNum,
LocationID) VALUES ('" + lblUTC.Caption + "',"
   'MsgBox s1
   's2 = curlat + "," + curlng + "," + curAlt
   s2 = lblLat.Caption + "," + lblLong.Caption + "," +
lblAlt.Caption
   'MsgBox s2
   s3 = ",'" + gShoreID + "','" + gGPSSerialNumber +
"'," + gLocationID + ")"
   'MsgBox s3
   mySQL1 = s1 + s2 + s3

   'MsgBox mySQL1


   myRs.Open mySQL1, myConn

  ' myRs.Close
  ' Set myRs = Nothing

   myConn.Close
```

Table 4.3: GPS Automated Entry

The Figure 4.11b is the Hydrolab manual entry screen. ENVITNote can record from the Hydrolab water quality sensor automatically. It simply records all measurements that it can sense upon request once. You may also use the manual entry screen to enter data by hand directly from the Hydrolab.

ENVITNote also has many manual inputs for external measurements a user might take. There are separate screens for Biology (Figure 4.12 a), Chemistry (Figure 4.12 b), and Flow (Figure 4.12 c). The embedded Visual Basic code which controls the data entry from these screens can be seen in Table 4.4. All three screens cannot be accessed until the user enters the width of the river and the number of subsections the user wants to record at this cross section. Next, the user selects a parameter to record. On the Biology screen the user can enter Bacteria (E. Coli and Total Coliform) and Algae (Chlorophyll and Blue-Green Algae). On the Chemistry screen, the user can enter Nitrogen (Nitrate NO3-, Nitrite NO2-, and Ammonia NH4+), Phosphorous (Phosphate PO4+2), and Metals (Aluminum Al+3, Cadmium Cd+2, Copper Cu+2, and Silica Si). The Flow screen simply allows the user to enter the flow. After the parameter is selected, the user is taken to a Cross-Section Screen (Figure 4.12 c shows the cross section screen for flow records). The user may click anywhere on this cross section and enter data for that subsection. The user will be prompted for the depth measurement. The user will also be prompted for a value taken at 20% depth of the measurement being recorded as well as a value at 80% depth. This data is recorded directly into the database. It is also averaged (with all other data ever collected in the database) for this cross-section.

```
   If (DataEntered2 = True) Then
   'For depth 20%
      mySQL1 = "INSERT INTO UIRecord
(Tstamp,iPaqIPaddress,KitSerialNum,UserID,Locat
ionID,MeasurementID,KitType,WidthInterval,
DepthInterval, Val, units, Latitude, Longitude,
Altitude, Depth) VALUES (" + _
            "'" + CStr(gTstamp) + "'," +
gIPaqIPaddress + "'," + gKitSerialNum + "'," +
gUserID + "'," + gLocationID + ","
      gMeasurementID = "7"
      mySQL2 = CStr(gMeasurementID) + ",'" +
gKitType + "'," + CStr(SelSec) + ",1," +
txtFlow20.Text + ",'m/s'," + CStr(Latitude) + "," +
CStr(Longitude) + "," + CStr(Altitude) + "," +
txtDepth.Text + ");"
      SubmitSQL (mySQL1 + mySQL2)
   End If
```

Table 4.4: Sub-Section Data Entry

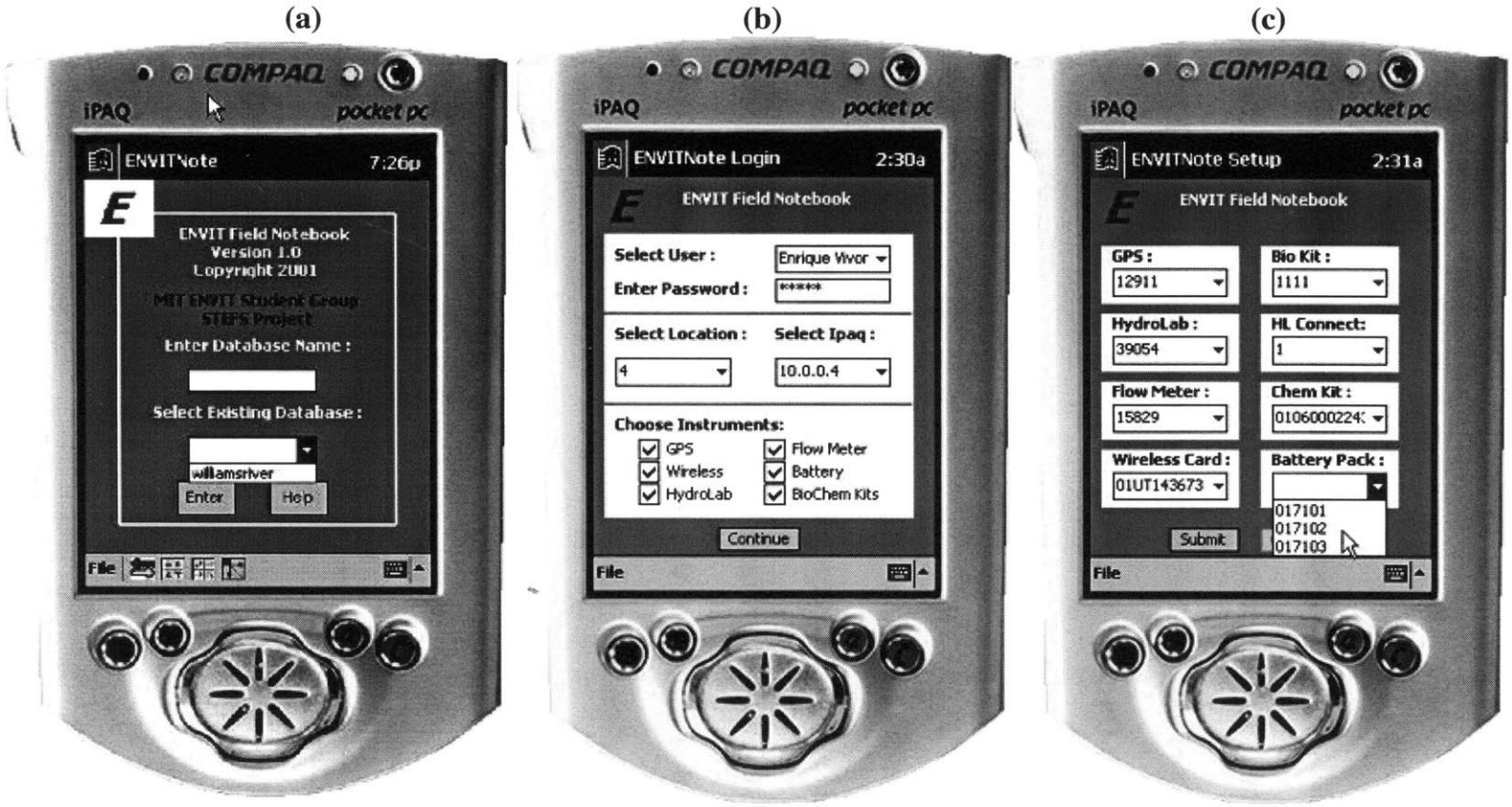


Figure 4.10: **a: Welcom Screen of ENVITNote**
b: Logjn Screen of ENVITNote
c: Equipment ID Screen of ENVITNote

Figure 4.11: **a: Automatic GPS Screen of ENVITNote**
b: Hydrolab Manual Entry Screen of ENVITNote

Figure 4.12: **a: Biology Manual Entry Screen of ENVITNote**
b: Chemistrey Manual Flow Entry Screen of ENVITNote
c: Flow Meter Manual Entry Screen of ENVITNote

4.8 Data Transmission

The ENVITNote Application has the capability of "Pushing" data to and "Pulling" data from the laptop mobile field server. The process is shown in Figure 4.13. When the user completes the welcome screen (Figure 4.10 a) the Windows CE Application running on the PocketPC (ENVITNote) signals to the SQL Server CE Client Agent (also running on the PocketPC) to request the database from the Field Laptop. After the PocketPC detects that it is within range of the wireless network and that the IP Address of the Field Laptop (the SQL Server CE Server Agent which it wishes to pull the database from) is reachable, it sends a request to the SQL Server CE Server Agent (on the Field Laptop) to transmit the data. The Server Agent accesses the SQL Server CE Database via the SQL Server ADO and retrieves the data to be sent. The data is then packetized and transmitted through the wireless network to PocketPC and the SQL Server CE Client Agent. The Client Agent then enters the data into its local database via the local Database Engine. See Table 4.1. The data is now available on the PocketPC for entry, viewing, and manipulation, as described in Section 4 of this chapter. Every time a record is changed or added to the local database, a note is also made in the database that this record needs to be updated in the server database.

Once the user has finished entering and manipulating data on the PocketPC, s/he can "Push" the data back to the Field Laptop using the ENVITNote Application. See Table 4.5.

```
    Case "mnuDataSubmit"
      Dim myConn As ADOCE.Connection
      Set myConn =
CreateObject("ADOCE.connection.3.1")
      myConn.ConnectionString = RemoteConn

      ' Push the databse back to the laptop
      myRDA.Push "Login", RemoteConn
      myRDA.Push "InstrumentRecord",
RemoteConn
      myRDA.Push "UIRecord", RemoteConn
      myRDA.Push "GPSRecord", RemoteConn
      myRDA.Push "Shore", RemoteConn

      MsgBox "Data Transfer Completed.",
vbOKOnly, "Message"
  End Select
```

Table 4.5: Push Data From Updated Tables

The application initiates its SQL Server CE Client Agent to gather data to be pushed from the local database via the local Database Engine. The PocketPC once again detects that it is on the wireless network and that the Field Laptop is on the wireless network as well. The Client Agent then packetizes the data and sends it to the Server Agent on the Field Laptop. The Server Agent then enters the data into the Field Laptops database via its SQL Server ADO. This data is now available to be pulled by other users or transmitted to the Web Server for viewing over the Internet.

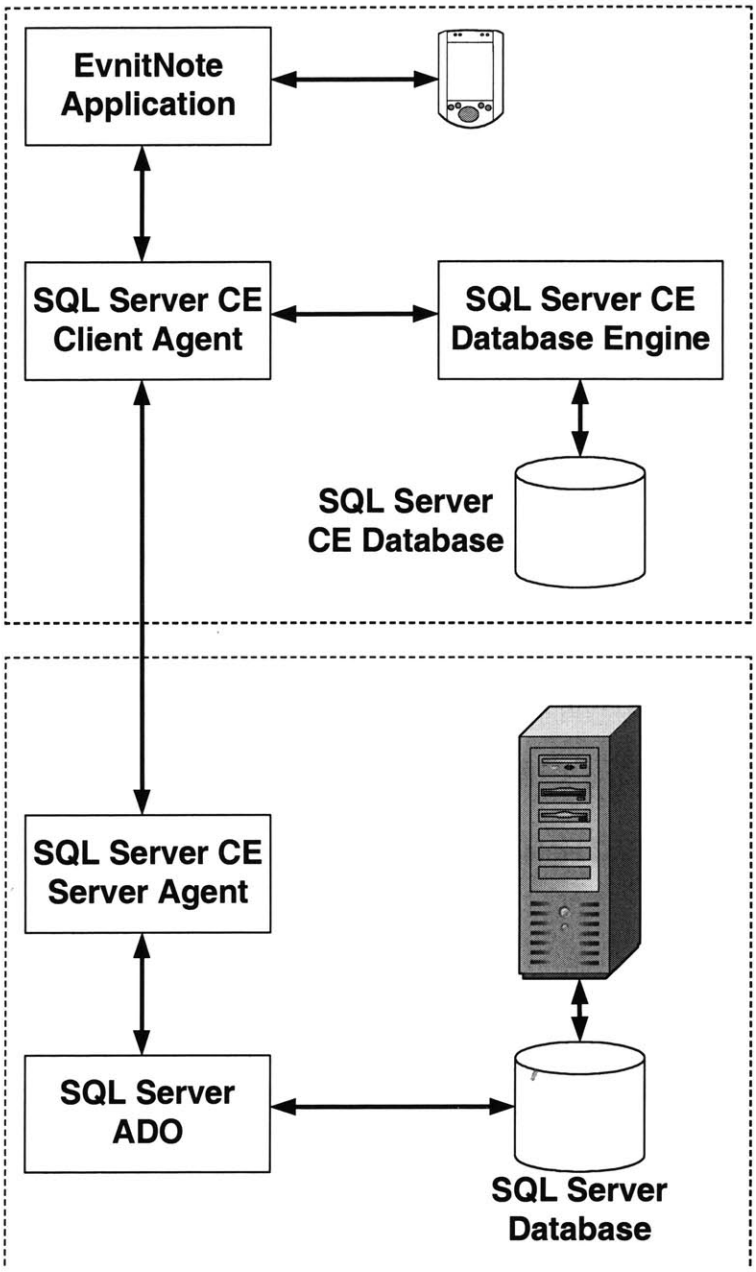


Figure 4.13: SQL Server CE Push Pull Model
Courtesy of C. Tsou, private communication, 2002

4.9 Cambridge Field Test

The data entry functions of ENVITNote Application were tested during the Cambridge Field Test. Overall the system worked quite well. Given the fact that most of the final preparations on the software had occurred only days before this test, the test can be considered a success.

There were two specific items that called for attention during the Cambridge Field Test. First the GPS functions (see Figure 4.11 a) were relatively non-operational and did not obtain a location fix. The ESRI Arcpad application, running on a PocketPC next to the PocketPC running ENVITNote and using the same GPS PCMCIA card was able to track the teams movements with a satisfactory accuracy. This indicated a clear problem with the GPS functions in ENVITNote. The resolution to this problem is discussed in section 4.11.

Second, there was also a problem with the log-in functionality (see Figure 4.10 b). The same user could not log in twice using the same iPaq at the same location. This was a problem, especially during the preliminary testing when logging out and logging back in to the system was a frequent occurrence. The resolution to this problem is discussed in section 4.11.

4.10 Newcastle, Australia Field Test

Unfortunately, due to time constraints, relatively little was doable to correct problems identified in the Cambridge Field Test before the Australia Field Test. As a result, the

same problems were prevalent in the Australia field test as well. An additional problem was identified during the Australia Field Test. Many of the measurements being taken for the study, including most biological and certain chemical measurements, were not available instantaneously. In fact certain biological readings were not available until 24 hours after samples were taken. As a result, both the live data entry and live data sharing capabilities of ENVITNote were jeopardized. With the system, as tested in Australia, it was not possible to enter data measurements, after one had left the site of data collection. As a result, data needed to be entered by hand directly into the database. This defeated the purpose of taking such readings through the ENVITNote system.

4.11 Revisions

The three problems identified during Field Testing with the ENVITNote System were addressed upon return from Australia. The problem of entering data after leaving the data collection site is relatively complicated and is addressed in detail in Section 12 of this chapter. The problems with the GPS and Log-in screens are less complicated and only involved simple fixes in the system.

Related to the first problem, the GPS functionality was not working because it was generating too many errors attempting to enter data in the database. These errors were being generated because the time that the GPS sensor was reporting was often invalid and not a legal entry into a date/time field of the database. To fix this problem, the ENVITNote application was revised to use the iPaqs local time when recording GPS

measurements. This ensured that the entries would not generate errors from the database, and resulted in a functional GPS module of ENVITNote.

Similarly, related to the second problem, the log-in functionality was also a simple fix. The same user could not log in twice using the same iPaq at the same location due to the fact that the primary keys of the log-in table were User, Location ID, and iPaq IP Address. To solve this problem, Log-In Time was also added as a primary key to this table to the database. This enabled the same user to log-in as many times as s/he needed to.

4.12 Integration of Post Processed Data

Samples are often collected in the field, which are not processed instantaneously. Samples can take hours or even days to analyze or incubate. Some samples may even need to be sent to a lab for analysis, in which case it may take weeks for the results to be determined. As a result, in order to integrate this type of data with the STEFS model, samples must be tagged with serial numbers, which must be entered into the PocketPC in the field in the place of actual measurements and stored with the project, equipment, user, and location information. Once the results are obtained, the user must be able to enter this data into a Windows Graphical User Interface by searching for the appropriate serial number and replacing it with the actual data. Finally, this data needs to be instantly updated in the output tables of STEFS for display on the GIS Web Services. As a result, an effort has been made to create a Windows Visual Basic Lab Data Entry tool and

modifications will be made to STEFS to allow it to collect serial numbers in place of data where appropriate.

The PocketPC application was modified to allow for both data and serial number entry for Biology and Chemistry readings. The modified screen is shown in Figure 4.14. This screen now replaces Figure 4.12 c. If the Data Entry radio button is selected, the software behaves exactly the same way as described in Section 7 of this Chapter. However, if the "Lab Specimen" radio button is selected, the system allows the user to enter a serial number into the text boxes. The intent is that the field researcher will write this serial number on the specimen, recorded it in the database.

Figure 4.14: Modified Data Entry Screen for Lab Data

After the lab specimen has been analyzed and the results are obtained, the field researcher can use the Visual Basic .NET search tool shown in Figure 4.15 to locate the specimen with the serial number s/he has entered. In case that serial number is misplaced, he may also search by User, LocationID, Kit Type, or MeasurementID. All of these pull down menus are populated from the database. Once the search button is pressed, the list box on the right of the screen is populated with possible serial numbers that match the search criterion. The user may then select the serial number, and replace it with the results of the specimen analysis. This data will be replaced in the database, and be ready for display by the GIS Web Service and ESRI ArcPad.

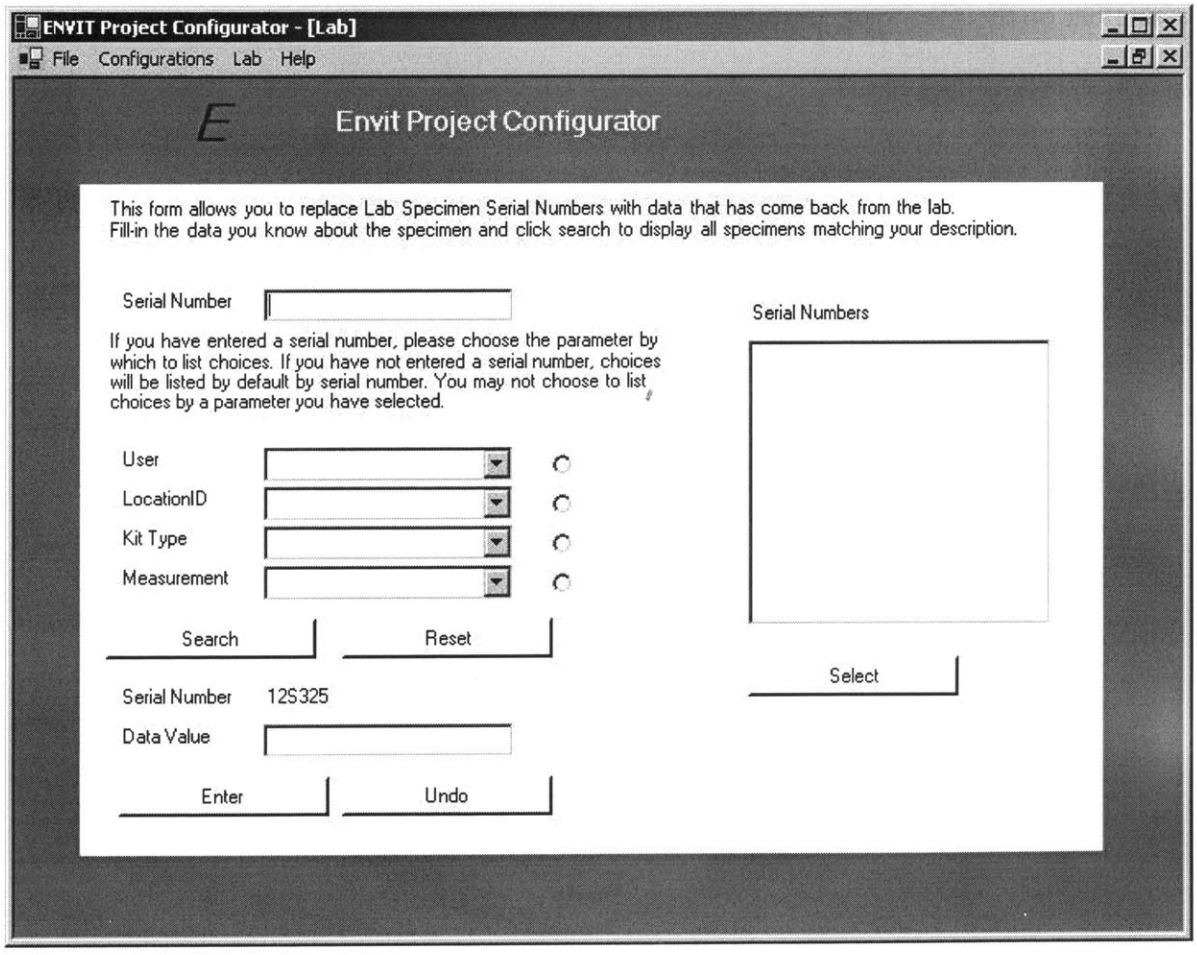

ENVIT Project Configurator - [Lab]
File Configurations Lab Help
Envit Project Configurator
This form allows you to replace Lab Specimen Serial Numbers with data that has come back from the lab.
Fill-in the data you know about the specimen and click search to display all specimens matching your description.
Serial Number
If you have entered a serial number, please choose the parameter by which to list choices. If you have not entered a serial number, choices will be listed by default by serial number. You may not choose to list choices by a parameter you have selected.
User
LocationID
Kit Type
Measurement
Search
Reset
Serial Numbers
Select
Serial Number 12S325
Data Value
Enter
Undo

Figure 4.15: Data Entry Screen to Replace Serial Numbers with Data

4.13 Conclusions

The SQL Server Database proved to be the central feature of the entire data collection system allowing all of the different types of data collection to occur, and be organized through the ENVITNote Application. All of the data that is collected through the system is well organized and easily queried. Tests indicate that no data was lost, and that the SQL Server Push-Pull system proved useful for transmitting data from PocketPCs to the laptop field server allowing for advanced data processing and sharing. Overall, the data collection power of the STEFS system is the core of its purpose and its usefulness.

CHAPTER 5: GEOSPATIAL DATA INTEGRATION

5.1 Introduction

This chapter explores how to associate location data with other data collected on the handheld computers and how to display that data on electronic maps. It describes the Geospatial Data Integration module used by STEFS to relate location data collected by the GPS sensor with environmental data collected manually by field researchers and automatically by the Hydrolab sensor.

This chapter is organized as follows. Section 5.2 describes the basic specifications and an analysis of the Teletype (http://www.teletype.com) GPS PCMCIA card being used in the system in order to understand what type of accuracy we can expect to be reported by that sensor. Section 5.3 discusses the preliminary design of using a C#.NET (a Microsoft programming language, http://msdn.microsoft.com) application to average location data, and Section 5.4 describes how that application can select the most accurate environmental data, and build an output table that relates the two data sets. Section 5.5 explains how the output table must be readable by GIS (Geographic Information Systems). Sections 5.6 and 5.7 of this chapter describe the two methods used in STEFS to display GIS data both on the PocketPC and on the Internet. Section 5.8 describes how this module performed during a field testing, and Sections 5.9 and 5.10 discuss the revisions and conclusions that were made as a result of this field testing.

Before this author joined the STEFS project, there had been a number of technological choices that had been made and were not subject to change. This chapter and this thesis

assume these choices are design constraints that will not be explored in this thesis. Some of these constraints include choosing ESRI (http://www.esri.com) ArcPad and C#.NET (http://msdn.microsoft.com) were chosen as the GIS display platforms for the STEFS system. Throughout this chapter, we then assume that ESRI ArcPad and C#.NET are fixed criterion in the selection of other components in the wireless system.

For advancements in the GIS map display media of STEFS, refer to "Integrating Real-Time Geo-Referenced Data Streaming into Interoperable GIS Web Services," Kolodziej, 2002 and "GIS Web Services using .NET Framework," Tsou, 2002.

5.2 Teletype GPS

GPS testing and correlating are key parameters towards determining the accuracy of the data that is recorded, and determining how much data we need to average to obtain result reliability.

We are using a Teletype (http://www.teletype.com) GPS 12911 PCMCIA Card. Teletype states that the accuracy of its product is 3m to 30m. The product states that it reports every 0.1 seconds, regardless of weather conditions. The operational temperature and humidity are respectively 0^{o}C-70^{o}C and 5% - 95%. A standard test of GPS accuracy is to study the variance in reported location on a static (not moving) GPS module that is not moving.

Three hours of GPS reporting were logged using a fixed Teletype GPS card attached to a PocketPC and ESRI (http://www.esri.com) ArcView software. The actual reporting frequency is on average 0.5 seconds, as opposed to the 0.1 seconds as suggested by the manufacturer. During the three hour test, ArcView logged approximately 2800 positions. This frequency is only about .8 seconds.

In the 2800 logged positions, the maximum discrepancy between points was approximately 30m. The maximum discrepancy from the mean point was approximately 19m. The standard deviation from the mean position was 4.67m. Figure 5.1 shows a plot of all the positions logged by the GPS sensor over 3 hours.

Figure 5.2 shows those same positions in a histogram as they deviate from the mean. For more information on Teletype GPS refer to, "GPS and Wireless Presentation, M.I.T., 2001," Spieler, Russell and http://www.teletype.com. For more information on GPS in general refer to http://www.trimble.com and http://www.gpsscales.com.

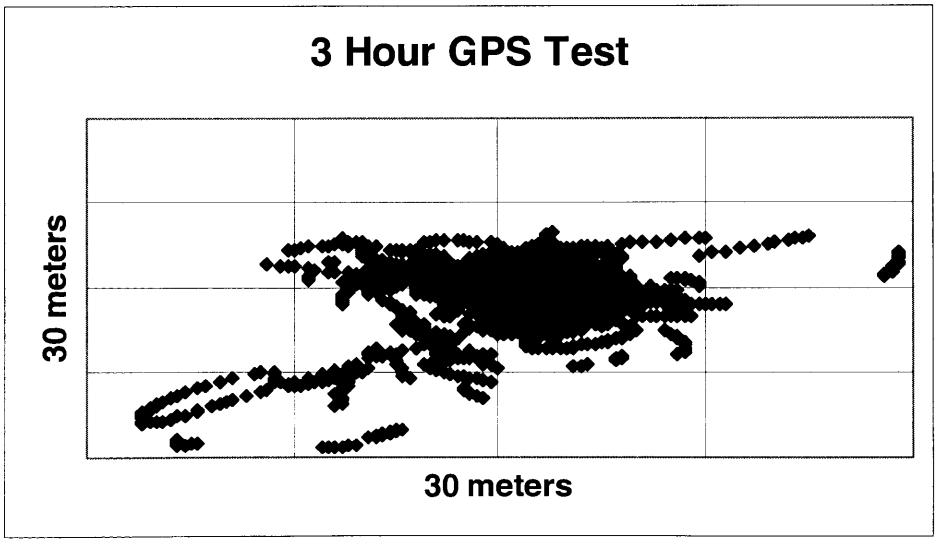


Figure 5.1: Logged Positions

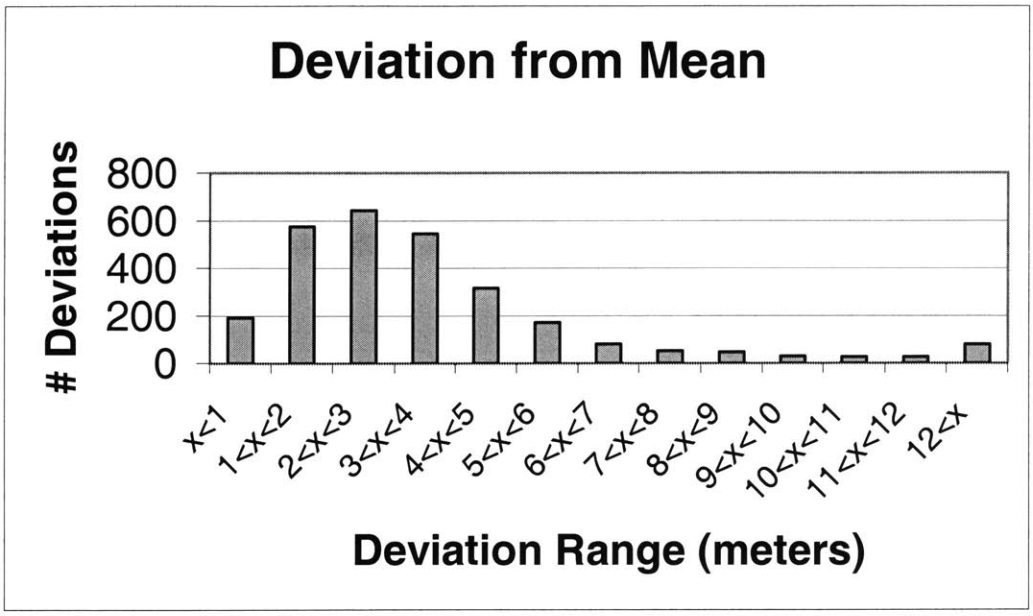


Figure 5.2: Histogram of Deviations

5.3 Early Design

Due to the inaccuracies of GPS data shown above, the geospatial data integration was based on averaging GPS data, and extrapolating the location of each data point from user input. The original design was to collect location data for both shores of each cross section of the river (see Figure 5.3 a). Taking the average of these data collections would return a relatively accurate estimate of where the team was on each shore (see Figure 5.3 b). Because it is unlikely that the data collection occurred exactly at the shore point, the actual shore points can be found by using the user input width of cross section (see Figures 5.3). We adjust the GPS averaged points to the actual shore points by moving D along the line between the GPS averaged points (see Figure 5.3 c). The distance to move D, is given by:

$$D = \frac{L - W}{2},$$

Where L is the distance between the averaged points and W is the width reported by the user interface for the session.

Once the system has an accurate GPS point for both shores, it is possible to associate each measurement marked on a sub-section of the cross section. The system simply divides the width by the number of subsections to obtain the interval width. It then designates a GPS location to each subsection by moving the interval width times the interval number away from the shore. Therefore, when the user enters the number of intervals and the width of the cross-section, each sub-section can be given a GPS point based on the averaged re-adjusted shore points and the line between them (see Figures 5.3, 5.4 and 4.12).

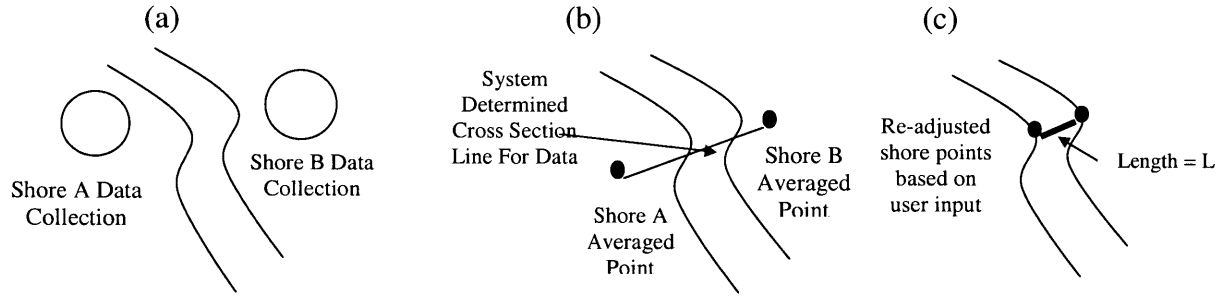


Figure 5.3: **a: GPS Data Collection**
b: GPS Data Averaging
c: Re-Adjustment of Shore Based On User Input

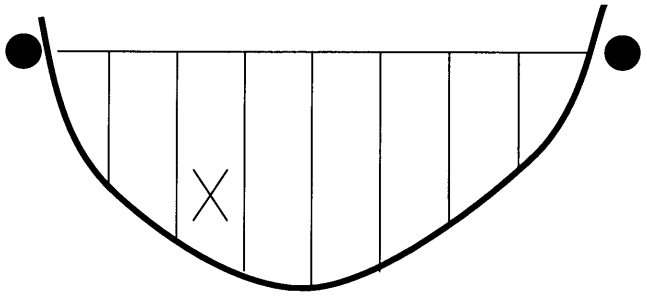


Figure 5.4: Cross-Section of River Divided Into Sub-Sections

5.4 Data Selection

Users can enter multiple data records for the same measurement at the same location. When this happens it may be difficult to determine which reading the user wants reported. While all data readings taken will be logged in the database, only one reading can be displayed for each measurement at a specific location on live displays of the data.

There are two primary intentions a user could have when entering multiple data records for the same measurement at the same location. One scenario is the old data was incorrect due to instrument malfunction or human error. In this case the user wants only the new data reported. A second scenario is that the user wants to be sure he got an accurate reading at a site and takes multiple readings, desiring to report the average of these readings.

Because there would be a large amount of overhead associated with maintaining these intentions for each measurement, the user must specify this while using the Configurator tool for all readings in the entire field study. Based on this decision, the system will only use either the most recent data or the average of all data for a location when setting up live data displays. For all field testing of this system, only most recent data was used for live display.

5.5 Creation of Output Table

The relational database is a robust means of collecting not only all the data, but all of the conditions surrounding the data collection. However, the relational database is not in the

right format to display data on a typical GIS display. Data is stored in the UI Record and Instrument Record tables without any geospatial data information as discussed in Chapter 4 exhibited in Figure 4.3. The GPS Records are stored in a completely separate table. To display GIS data using a typical GIS data display, the data must be in the following format:

X	Y	Measurement 1	Measurement 2	Measurement 3	Measurement N

The original method of creating an output table was to use a C#.NET application running on the field laptop to process the data and create an output table. This application would process all data it had obtained from the PocketPCs every minute. The following steps need to occur to ensure that all data at all points entered are displayed:

1. After the PocketPC application completes a GPS data collection for a shore, it averages that data and enters it into the Shores table.
2. The first thing the Windows application on the laptop does is import this shore data and moves the averaged points to the actual shore points using the cross-section width as described in Section 3 of this Chapter.
3. It then maps each UIRecord to a GPS coordinate based on the shores and the width interval.
4. It clears everything from the previous output table to be sure it is writing only unique entries.
5. Next it fills in the table with the distinct GPS coordinates created from UIRecord.

6. Finally it reads through each value in UIRecord and Instrument Record and fills it in the table next to the appropriate GPS point.

Unfortunately, the C#.NET program was never fully debugged. As a result, no data was actually displayed live during either field test. The method used in Section 9 of this chapter describes an alternate method of creating the output table. This method has been created and debugged after the field tests and is currently operational.

5.6 Display through GIS Web Service

The GIS Web Service takes the most recent data in the web server's database and displays it on a background image on demand (see Figure 5.5). Once the data is available in the format (shown in Section 5) for display on a GIS map, the GIS Web Service is able to take this data, translate GPS positions to pixels, and display shades of color overlaying the background image indicating the range of readings at that point. The Web Service allows the user to request a specific data set for a specific measurement. It then generates a bitmap image of the background map with shaded colors representing data at appropriate pixels (GPS locations). It also creates a legend indicating which shade of color represents which range of values. Finally, it displays these images on the user's browser.

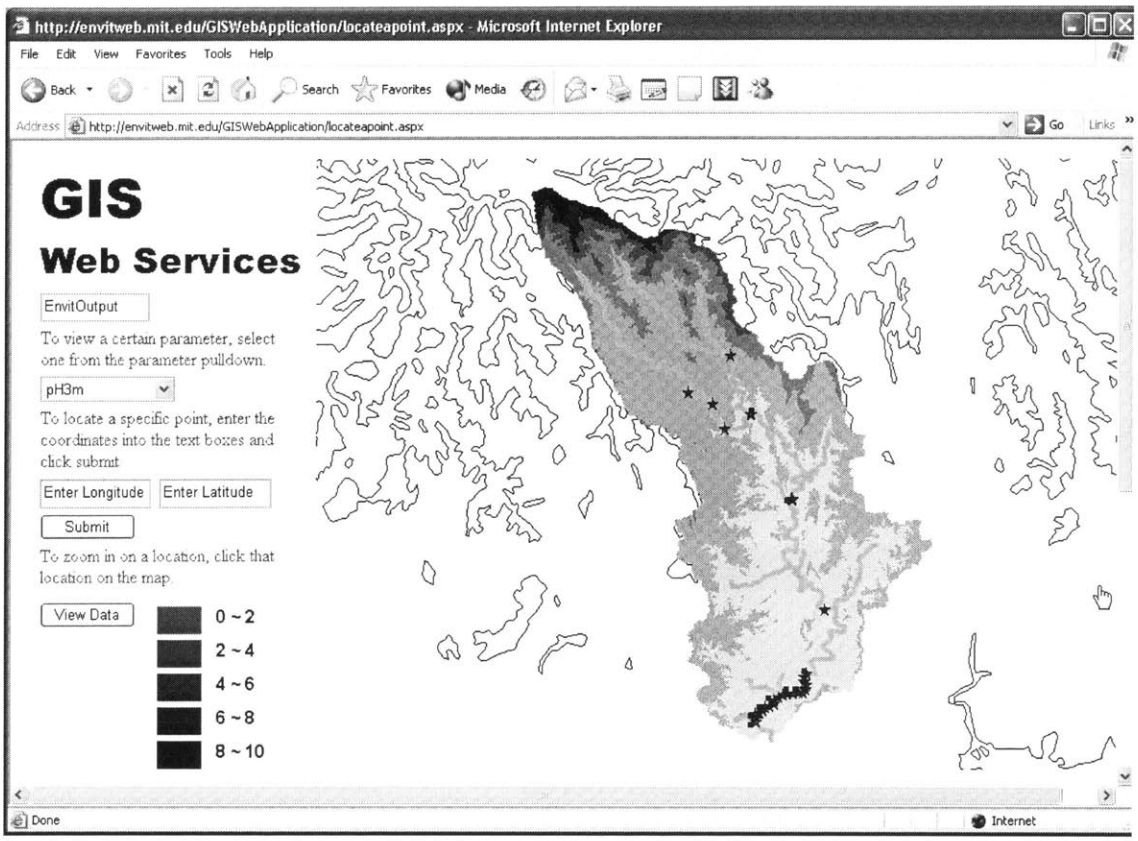


Figure 5.5: GIS Web Service, Australia Field Study

5.7 Display through ESRI ArcPad

One of the major benefits of using a system that can display live data is that researchers can share data live in the field and modify their study based on this data. Once the data is available in the format (shown in Section 5) for display on a GIS map, ESRI (http://www.esri.com) ArcPad can be programmed using Visual Basic Scripts to accept data and display it on a background image. The scripts simply place the data points on a geo-referenced background image (see Figure 5.6). Unfortunately, due to time constraints, we were not able to program these scripts to be compatible with a SQL Server Database, nor were we able to program the ENVITNote application to provide a

Figure 5.6: Display of Data Using ESRI ArcPad

copy of the output table in a compatible format for these scripts to read. Therefore, while ESRI ArcPad was used to verify the proper function of the GPS sensors, it was not used as a live display tool for researchers to share data in the field. Researchers were however able to view some data using the GIS Web Services and Microsoft Pocket Internet Explorer (a standard browser available on the PocketPC). This was only possible due to a locally generated GIS Web Service on the field laptop available only to viewing by the PocketPCs with WLAN.

5.8 Newcastle, Australia Study

The GIS Web Services were not available for the Cambridge Field Test. The first time they were used was during the Newcastle, Australia study. Because we were unable to have the C#.NET data processing application debugged on time, the Web Services were

not actually live during the field test. Instead, at the end of each day, data was transcribed by hand from the database to the GIS Web Service's output table on the Web Server using remote log-n. While it was not live and automatic as had been desired, it did show that data could be displayed on the Internet while the field study taking that data was still underway. Users of the service were able to see the data collected in the field the previous day, and locate exactly where the field teams had been on a map.

5.9 Revisions

As was mentioned in Section 5 of this Chapter, the original method of creating an output table was not debugged, and was eventually discarded as a feasible means of sorting the data in the tools of this thesis. As a result, a new method of sorting the data had to be created. The new method is far simpler than the C#.NET method, but has limitations. It does not attempt to map each value to a GPS point representing a sub section of a cross section. It only maps average data for each cross section at the center point of the two shores for that cross section. This makes the process simpler because we know how many points we will have before we begin the field study. Each LocationID corresponds to a cross section and only one GPS point. These Location IDs are assigned prior to field study departure. As a result, we are able to fill in the output table using the PocketPC application. This involves minimal additional calculations. Basically, every time a Shore GPS location is calculated, the system updates the GPS location for that LocationID. Similarly, anytime a UIRecord or InstrumentRecord is entered, the system recalculates the average for that measurement over the cross section and records the new average for that measurement and LocationID in the output table. The data from the output table is

"pushed" back to the laptop (See Section 4.8), with the rest of the tables and integrated with the output tables from the other PocketPCs. This data is now ready for display by the GIS Web Services (Section 6) and ESRI ArcPad (Section 7).

5.10 Conclusions

The data collected by STEFS is not in the correct format to display on a GIS display. The original method of integrating the Geospatial Data to process it into the correct format for GIS display was to use a C#.NET application on the laptop. Implementing this C#.NET data processing application proved more difficult than originally anticipated. As a result, the data display capabilities of STEFS were unfortunately not available during the field tests. The revised method of Geospatial Data Integration is much simpler than the C#.NET method and occurs locally on the PocketPC. The final system accomplishes the system goal of displaying the data in near real-time on the Internet, using this new method of Geospatial Data Integration.

CHAPTER 6: COMPARISON OF STEFS WITH SIMILAR SYSTEMS

6.1 Introduction

This chapter seeks to explore how this solution compares with other solutions. It attempts to compare STEFS with similar systems through a cost-benefit analysis. Section 6.2 describes the benefits of STEFS as an environmental field data collection tool. Section 6.3 analyzes the costs of its development and deployment. Section 6.4 discusses similarities and differences with other systems. Finally, Section 6.5 explores alternative uses of the technology used in STEFS.

6.2 Benefits of STEFS

There are three main features of the STEFS field data collection system that make it superior to the traditional field study: automated data entry, near real-time data sharing amongst field researchers, and near real-time data sharing to the Internet. The automated data entry feature of STEFS will result in less human errors that might have previously occurred during transcription of data, or even manual reading of instruments and maps. The automated data entry will also lead to less man-hours in the field because many measurements (especially GPS) are taken without the need for human intervention. The automated data entry also means there is no need to transcribe data from written notes to a computer for analysis and legibility. This eliminates the need of a human task, which was previously required during a field study.

Sharing data near real-time amongst field researchers will also save time in the field. Researchers will not have to wait until they are back to a computer to analyze the status of the field study. This means that if they are collecting data at a site and realize an interesting or important discovery, they can continue to take more data at that site before moving to another site to ensure they gather the data they need to analyze that discovery. Alternatively, if one researcher realizes a discovery and another researcher notices little or no data of interest at their site, the researchers can modify their data collection plans to study some sites in greater details than other sites.

Sharing data in near real-time on the Internet also saves time and allows for greater flexibility in the project. Typically, a sponsor of a field study does not see the results of the study until well after the study is completed. Sharing data in near real-time on the Internet allows the sponsor to see the data in near real-time, and order modifications on the study while the researchers are still in the field. It also allows data analysts to begin studying and processing the data while the study is still occurring, allowing for a shorter time period before results can be found. Finally, because the PocketPC data is sent back both to the field sever, and to the web server, three copies of the data are maintained at all times. This provides back-up in case data is lost on any machine.

6.3 Costs of Development and Deployment

Product development costs can be broken into the time that people put into building the system and the equipment they used to develop the system. Between Professors, Doctoral, Meng, and Undergraduates students, more than 6600 man-hours were put into

the development of STEFS. Using the pay scales shown in Table 6.1, the 6600 man-hours translates to $183,820. The equipment purchased to develop the system totaled $24,585. This leads to $208,405 total development costs, not including the valuation of time and money spent on testing it in Australia.

Level	Number	Hours Per Week	Value per Hour	Total Per Week
Professors	4	4	$100	$1,600
Doctoral Students	2	30	$50	$3,000
Meng Students	6	40	$30	$7,200
Undergraduates	13	15	$12	$2,340
		Total Per Week		**$14,140**
		Weeks		13
		Total Work		**$183,820**
		Six Loaded PocketPC System		$24,585
		TOTAL		**$208,405**

Table 6.1: STEFS Development Costs

Product deployment costs (shown in Table 6.2) can be alternatively broken down into the fixed costs of having a base station, and the variable costs of each deployment team, as different field studies will require a different number of field teams. As shown, the Hydrolab water quality sensor is the bulk of the deployment costs. The Hydrolab is the only interchangeable item in the system. One may purchase alternative sensors that collect water quality data for different costs. Therefore, it is reasonable to analyze the costs with, and with out, the Hydrolab. So a three-team system with Hydrolabs would cost around $18,000 without software (see Figure 6.2 = Fixed Cost plus 3 times variable costs). A three-team system with out Hydrolabs would cost around $9,000 without software.

Fixed Costs		Variable Costs	
Item	**Cost**	**Item**	**Cost**
Web Sever	$1,500	PocketPC	$400
Laptop	$1,500	PCMCIA Pack	$200
Wireless Router	$1,200	GPS Card	$500
Wireless Card	$100	Wireless Card	$100
1-Watt Amplifier	$575	Hydrolab	$3,000
15dB Antenna	$210	Case	$50
TOTAL	$5,085	TOTAL	$4,250

Table 6.2: STEFS Deployment Costs

6.4 Similar Systems

While there are many systems which allow for environmental data collection on a Windows based system, there are very few that allow for environmental data collection on a PDA based system. To the author's knowledge, there are only two systems which allow users to enter environmental data through a PDA: Environmental Science Research Institute's (ESRI http://www.esri.com) ArcPad, and Rockware's (http://www.rockware.com/) Field Data Recorder (FDR).

The primary PDA-based system used in practice in the environmental data collection field is Rockware's (http://www.rockware.com/) FDR. While FDR has a user interface for data collection using an MS Access Database with back-up and GPS/GIS inputs, the system lacks many of the features that STEFS has. Primarily, Rockware's (http://www.rockware.com/) system is neither live nor automatic. Their system does not

take automatic input from sensors, is not wireless, and cannot have multiple users transmitting data simultaneously. In addition, Rockware (http://www.rockware.com/) relies on MS ActiveSync and MS Access as the backbone of their system where as STEFS uses HTTP and SQL Server CE, allowing multi-thread data transmissions so that multiple PocketPCs can communicate simultaneously. Table 6.3 compares STEFS to FDR.

Feature	ENVIT (STEFS)	FDR (RockWare)
User Interface	**Yes**	**Yes**
Database	SQL Server CE	MS Access
Wireless	**Yes**	**No**
Multi – thread	**Yes** (HTTP)	**No** (ActiveSync)
Data Collection	Manual / Auto	Manual
Voice Recording	**Yes**	**Yes**
Backup DB	**Yes**	**Yes**
GPS / GIS	**Yes**	**Yes**

Table 6.3: STEFS Comparison to FDR

ESRI'S (http://www.esri.com) ArcPad also allows for environmental data entry. ArcPad's focus is on displaying collected data on an electronic map. Users can click directly on a map and using layers, enter the data for a specific measurement at any point. Integration with GPS sensors allow the user to know where they are and enter the data for that location. ArcPad does not make use of wireless technologies. It does have an abundance of Windows-based and Web-based applications which can interact with data collected in ArcPad such as ArcIMS and ArcView. STEFS main benefits over ArcPad is

the ability to maintain verification records. STEFS is capable of validating all data as it is entered and maintaining records on who entered the data and using what instruments. Finally, ArcPad does not readily lend itself to connecting sensors (other than GPS) directly to the PDA for automated input where STEFS makes use of automated inputs from Hydrolab water quality sensor.

6.5 Alternative Uses of STEFS Technology

The product has the potential to be adapted for numerous other data collection efforts. While the system is specifically tailored towards GIS data, it can be used to collect and share data of any kind. Some application domains are:

- Shipping Logistics;
- Inventory Management;
- Emergency Management;
- Environmental Emergency Management;
- Military Coordination;
- Vehicles Dispatching;
- Public Transportation Monitoring;
- Construction Management;
- Infrastructure Management;
- Equipment Monitoring;
- Medical Patient Management; and
- Utilities Management.

ACKNOWLEDGEMENTS

The ENVIT student group at MIT designed this system under the direction of Enrique Vivoni and Richard Camilli. The project was funded by a grant from the Microsoft I-Campus. The Sentient Vehicle Project at MIT sponsored the SafeRide adaptation under the direction of Professor Ismail Chabini. It was completed in conglomeration with the ShuttleTrack Microsoft I-Campus Project, MIT Transportation Office, and with the help of the MIT Earth Atmosphere and Planetary Sciences Department.

Concept of Mobile Field Notebook Application On PocketPC

Enrique Vivoni (ENVIT President) and Richard Camilli (ENVIT Vice President) developed the concept of a Mobile Field Notebook Application on a PocketPC.

Assembly of a I-Campus Project, Undergraduate Class, Graduate Researchers and Advising Staff

Enrique Vivoni (ENVIT President) and Richard Camilli (ENVIT Vice President) coordinated the assembly of the project team. Enrique Vivoni and Richard Camilli directed Eric Lau, Kevin Richards, Neeraj Agarwal, Ching-Huei Tsou, Russell Spieler, and Kris Kolodziej as the project integration team for the entire project.

Design and Development of ENVIT Database

Russell Spieler, Neeraj Agarwal, and Ching-Huei Tsou developed the ENVIT Database with assistance from the ENVIT Officers and Advising Staff.

Design and Development of Wireless Systems

Russell Spieler developed the wireless systems with assistance from Richard Camilli (ENVIT Vice President).

Design and Development of ENVITNOTE Graphical User Interface

Enrique Vivoni (ENVIT President) lead Amy Watson, Kim Schwing, and Nancy Choi in development of the ENVITNote GUI with guidance and development from Russell Spieler, Neeraj Agarwal, Ching-Huei Tsou and Kris Kolodziej.

Design and Development of ENVIT Configurator Graphical User Interface

Kris Kolodziej designed and developed the ENVIT Configurator with assistance from Russell Spieler.

Field Testing In Cambridge and Australia

The MIT Parsons Lab funded the Cambridge and Australia Field Tests under the direction of Professor Sheila Frankel and coordination with Enrique Vivoni (ENVIT President) and Richard Camilli (ENVIT Vice President). Kevin Richards and Eric Lau completed land use analysis to determine which sites were best for sampling and completed analysis and modeling of the data collected. The entire ENVIT student group contributed to the field testing including: Enrique Vivoni, Richard Camilli, Neeraj Agarwal, Kevin Richards, Ching-Huei Tsou, Russell Spieler, Eric Lau, Kris Kolodziej, Anna Leos-Urbel, Trisha McAndrew, Laura Rubiano-Gomez, James Brady, Brian Loux, Linda Liang, Aurora Kagawa, Arthur Fitzmaurice, Chrissy Dobson, Lisa Walters, Amy Watson, Kim Schwing, and Nancy Choi.

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Concept of adapting ENVIT to Track MIT SafeRide

Professor Ismail Chabini developed the concept of adapting ENVIT to track on SafeRide. Russell Spieler organized and implemented the adaptation.

Other Acknowledgements

Significant work, not mentioned in this paper, was completed by MIT undergraduates. Arthur Fitzmaurice, Chrissy Dobson, and Lisa Walters under the direction of Richard Camilli and Neeraj Agarwal worked on integrating the Hydrolab water quality sensor with the PocketPC. Brian Loux, Linda Liang, and Aurora Kagawa under the direction of Daniel Sheehan and Russell Spieler worked on integrating the GPS sensor with ESRI Arcpad and displaying data on ESRI Arcpad. Trisha McAndrew, Laura Rubiano-Gomez, and James Brady worked under the direction of Richard Camilli and Professor Shiela Frankel to research and modify field equipment to be brought on the field study.

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Arthur Fitzmaurice, Chrissy Dobson, Lisa Walters, Amy Watson, Kim Schwing, and Nancy Choi; and Undergraduate Researchers: Keyuan Xu, Rose Liu, and Kan Liu.

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http://www.esri.com

http://www.gpsscales.com/

http://www.hydrolab.com

http://www.hyperlinktech.com

http://www.microsoft.com

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GLOSSARY

802.11b – A wireless data transmission protocol that transmits data at a rate of 11 megabits per second on the 2.4 gigahertz radio frequency.

C#.NET – C# is a programming language released in 2001 by Microsoft. It runs on the .NET platform (see .NET).

CDPD (Cellular Digital Packet Data) – A system that adds to traditional digital wireless voice technologies in the US. It offers data rates of 19200bps and per kilobyte billing (as opposed to per minute billing).

ENVIT (Environmental Information Technology) – A Massachusetts Institute of Technology Association of Student Activities recognized student group dedicated to use of information technology for environmental purposes.

ENVIT Configurator – A Visual Basic .NET application, running on a Windows operating system, used to pre-configure the ENVIT database with equipment and people involved with a project before the actual field study.

ENVITNote – An Embedded Visual Basic application, running on a PocketPC, used to enter data into and transmit data from the PocketPC.

ESRI (Environmental Studies Research Institute) – A company in California whose products include Geographic Information Systems software for environmental field research.

eVB (embedded Visual Basic) – eVB is a programming language released in 2001 by Microsoft. It runs on the PocketPC platform (see PocketPC).

GHz (Gigahertz) – A frequency of a billion Hertz

GIS (Geographic Information Systems) – Any system which allows for association of experimental or recorded data with geographical location data.

GPRS (General Packet Radio Service) – A system that adds to traditional digital GSM wireless voice technologies. It offers data rates of 64kbps and per kilobyte billing (as opposed to per minute billing).

GPS (Global Positioning Systems) – GPS is a constellation of 24 satellites which allows for worldwide navigation using radio receivers on the ground.

GSM (Global System for Mobile Communication) – GSM is the primary wireless transmission medium in Europe, Asia, and Africa with limited build out in the US.

GUI (Graphical User Interface) – A graphical user interface is the part of a software application which allows the user to interact with the software.

iPaq – A personal digital assistant (see PDA) made by Compaq running the Windows PocketPC (see PocketPC) operating system.

iRDa (Infra Red Data Association) – A data transmission protocol that uses infrared light.

Mbps (Megabits per second) – Mbps is a rate of data transfer of a million bits per second.

MIT – The Massachusetts Institute of Technology located in Cambridge, Massachusetts where this paper was written and the research for this thesis conducted.

.NET - .NET is a set of Microsoft software technologies for connecting the users' world of information, people, systems, and devices.

Orinoco COR-1100 – A device called a wireless router, made by Orinoco, which can communicate with many mobile computers simultaneously using 802.11b (see 802.11b).

Orinoco Silver 802.11b Wireless PCMCIA Card – The Silver 802.11b Wireless PCMCIA Card is a PCMCIA card developed by Orinoco to transmit data from its host device wirelessly to another 802.11b receiver, such as the Orinoco COR-1100.

PCMCIA (Personal Computer Memory Card International Association) – PCMCIA is a standard for small, credit card sized devices to add features, ports, and / or memory to a computer.

PCMCIA Expansion Pack – A sleeve which holds the iPaq and a PCMCIA card, allowing the two of them to communicate through metallic contacts and conduits.

PCMCIA Dual Expansion Pack - A sleeve which holds the iPaq and two PCMCIA cards, allowing the two of them to communicate through metallic contacts and conduits.

PDA (Personal Digital Assistant) – A PDA is a handheld computer that can be connected to desktop computers to upload and download information.

PocketPC – A Microsoft Windows Operating System designed to run on PDAs (see PDA).

SafeRide – A free shuttle bus service that provides safe transportation for MIT students between their dorms and campus.

STEFS (Software Tools For Environmental Field Studies) – A system of hardware and software used to collect environmental and positional data on a PDA and transmit it back for processing and distribution to the Internet.

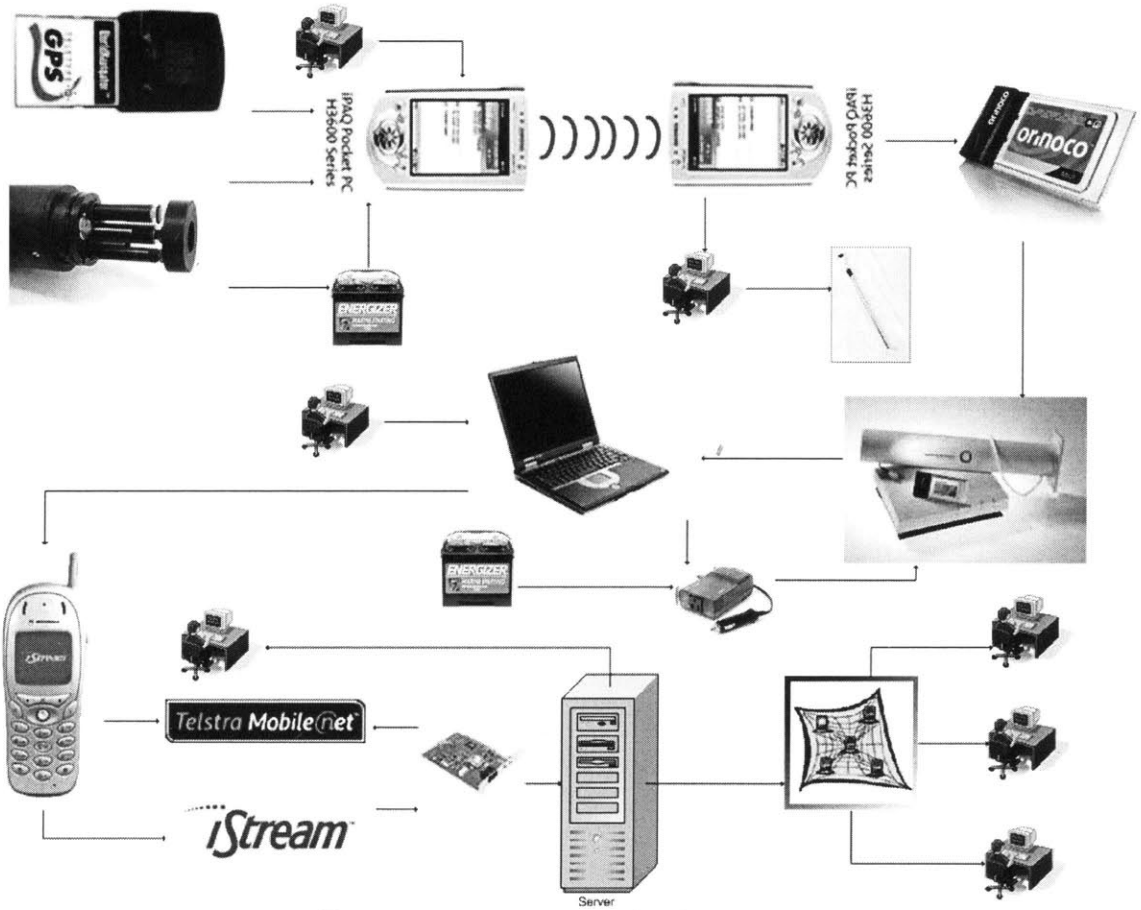
VB.NET (Visual Basic .NET) – Visual Basic is a programming language by Microsoft. It runs on the .NET platform (see .NET).

WLAN (Wireless Local Area Network) – A network connecting a group of computers over a small area using high frequency radio waves as the communications medium.

APPENDIX

Wireless Funding Proposal
STEFS Meng IT Project

In order to seamlessly share data amongst scientists, both in the field and at home, it is necessary to develop a wireless communications network. We intend to implement data transfer from the PocketPC to the World Wide Web, and ideally this data will be instantaneously available at a workstation for processing, manipulation, and output. This network will transmit data from the PocketPC to a field laptop, and from the field laptop to a server via wireless modem or wireless Local Area Network. Designing this network will necessitate tradeoffs between data processing capabilities, cost, wireless coverage, and necessary equipment in the field. Due to funding restrictions, this proposal has been revised and the overall cost of the project was cut by almost $2000.



Envisioned Hardware Architecture

Ipag to Field Laptop Connectivity ($2100)

After careful consideration of wireless options for the STEFS project we have chosen the ideal solution for data transmission between Pocket PCs and a lap-top and between the lap-top and the main server back at MIT. We propose to use the Lucent Orinoco COR-1100 (848591152) and Orinoco PC Card FCC – Silver (848441481) to transmit data over 802.11b protocol from the PocketPC's to the field laptop. This product is the only product which allows for wireless communications from the field. After studying wireless service plans in Australia, none (with the exception of Satellite Phones) has solid service in the area we will be investigating. Normal 802.11b data access points, such as the type recently deployed around MIT's campus, only have a range of about 300 feet. Even more powerful standard access points only allow for 3000 feet maximum. Investigators will be traveling well over a mile from the field laptop with their PocketPCs. The Orinoco COR-1100 is the only WLAN product that has enough range (16 miles) to reach our investigators in the field. To use this product we need Orinoco Wireless PC Cards in each PocketPC. To use these PC Cards in conjunction with the Teletype GPS cards (already in use) we will need the Dual-Slot PC Card Expansion Pack for each PocketPC.

The proposed spending is as follows (www.nxgenstore.com) 1-800-860-4411**:**

~~1 x Lucent Orinoco COR-1100 (848591152) $1,216.99 (www.computers4sure.com)~~

1 x Lucent Orinoco COR-1100 (848591152) $1,100.00

~~6 x Lucent Orinoco PC Card FCC – Silver (848441481) $89.95 each $539.70 total~~

~~3 x Lucent Orinoco PC Card FCC – Silver (848441481) $89.95 each $269.85 total (www.computers4sure.com)~~

4 x Lucent Orinoco PC Card FCC – Silver (848441481) $72.64 each $290.56 total

1 x 11inch IEEE Jumper / Pigtail N-Female (WRJCMW11F) $39.17
1 x HyperGain 15DB OmniDirectional Antenna (HG2415U) $201.00

Approximately (including tax and shipping) $1650

The proposed spending is as follows (www.compaq.com):

~~6 x 216198-B21 – Dual-Slot PC Card Expansion Pack $199.00 each $1194.00 total~~

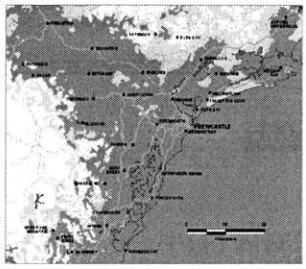
~~3 x 216198-B21 – Dual-Slot PC Card Expansion Pack $199.00 each $597.00 total~~

3 x 170338-B21 PC Card Expansion Pack $150 each $450 total

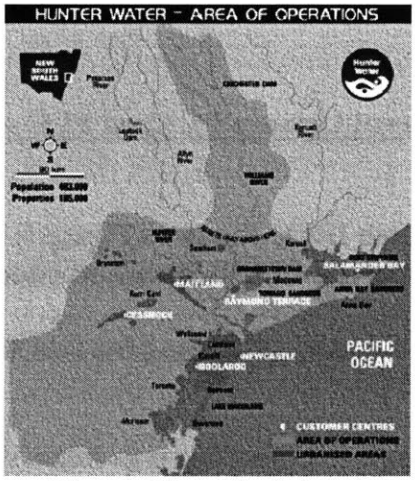
Total for PocketPC to Field Laptop $2100

Field Laptop Web Server Connectivity ($1075)
GSM/GPRS vs Satellite

As mentioned earlier, the only wireless service available in the area we will be investigating will be with dependable coverage is Satellite phones provided by GlobalStar. GSM / GPRS coverage by Telstra may, however, be reasonable in the Hunter Watershed area for a proof of concept.



Telstra GSM Coverage Area
(Scaled to Size of Complimentary Map)
(See Appendix I.I for Full Size Coverage Map)



Hunter Watershed Area

As shown the GSM coverage area may be enough to have coverage some of the time for the field laptop and allow for some proof-of-concept testing in Australia. Satellite phones have ubiquitous coverage over all areas. The following table will allow us to analyze the benefits of each system.

Feature	Satellite	GSM/GPRS
Coverage	100%	Possibly Spotty
Price	$1624 (see Appendix I.III)	$1096.90
Usage	50mins/month	10MBs/month
Extra Use Cost	$1.39/min	$4.00/MB
Use Cost in Australia	$2.39/min x 40mins = $95.60	$10.00/MB x 10MB = $100.00
Data Rate	19.2kbps	Up to 64kbps w/ GPRS

Satellite vs GSM/GPRS Data Connectivity

Although there are some benefits to using a satellite phone, the cost difference is substantial. It is therefore recommended that we use GSM/GPRS service provided by Telstra (900MHz) in Australia and VoiceStream (1900Mhz) in Boston (See Appendix I.II for VoiceStream's Boston Coverage Map).

Field Laptop Web Server Connectivity
Motorola P280 vs Ericsson T28W

Since we are currently in the Boston and need to test our product in the Boston, we will have to purchase our phone and our service in Boston. VoiceStream (the main carrier of GSM/GPRS in Boston) only offers two data-enabled phones which will operate on both the 1900MHz and 900Mhz systems. These are the Ericsson T28W and the Motorola P280 (aka the Motorola Timeport 280). The following table compares the two phones.

Feature	Ericsson T28W	Motorola
Data Connectivity	Directly to Phone (or PocketPC)	Via Attached Infrared Modem
Network Capability	GSM	GSM/GPRS
Price for Equipment and Service	$500 (see Appendix IV)	$1096.90
Data Rate	9.6kbps	Up to 64kbps w/ GPRS

Ericsson T28W vs Motorola P280

The proposed spending is as follows (1-888-STREAMS):

1 x Motorola P280 (Timport 280) GSM/GPRS Tri-Mode (1900/1800/900MHz) Phone	$169.99 (VoiceStream)
1 x Motorola Data Connectivity Kit	Included
~~1 x SIMM Card~~	~~$30???~~
12 x 1 Month VoiceStream Service Charges (10MB/60mins/500mins/month)	$59.98/month $719.76 total (VoiceStream)
10 x Estimated MB while in Australia	$10/MB $100 total (VoiceStream)
Total for Field Laptop to Web Server	$1000 + tax and shipping

Approximately $1075

Customer Service: 1-800-937-8997 ****
Order # 513728

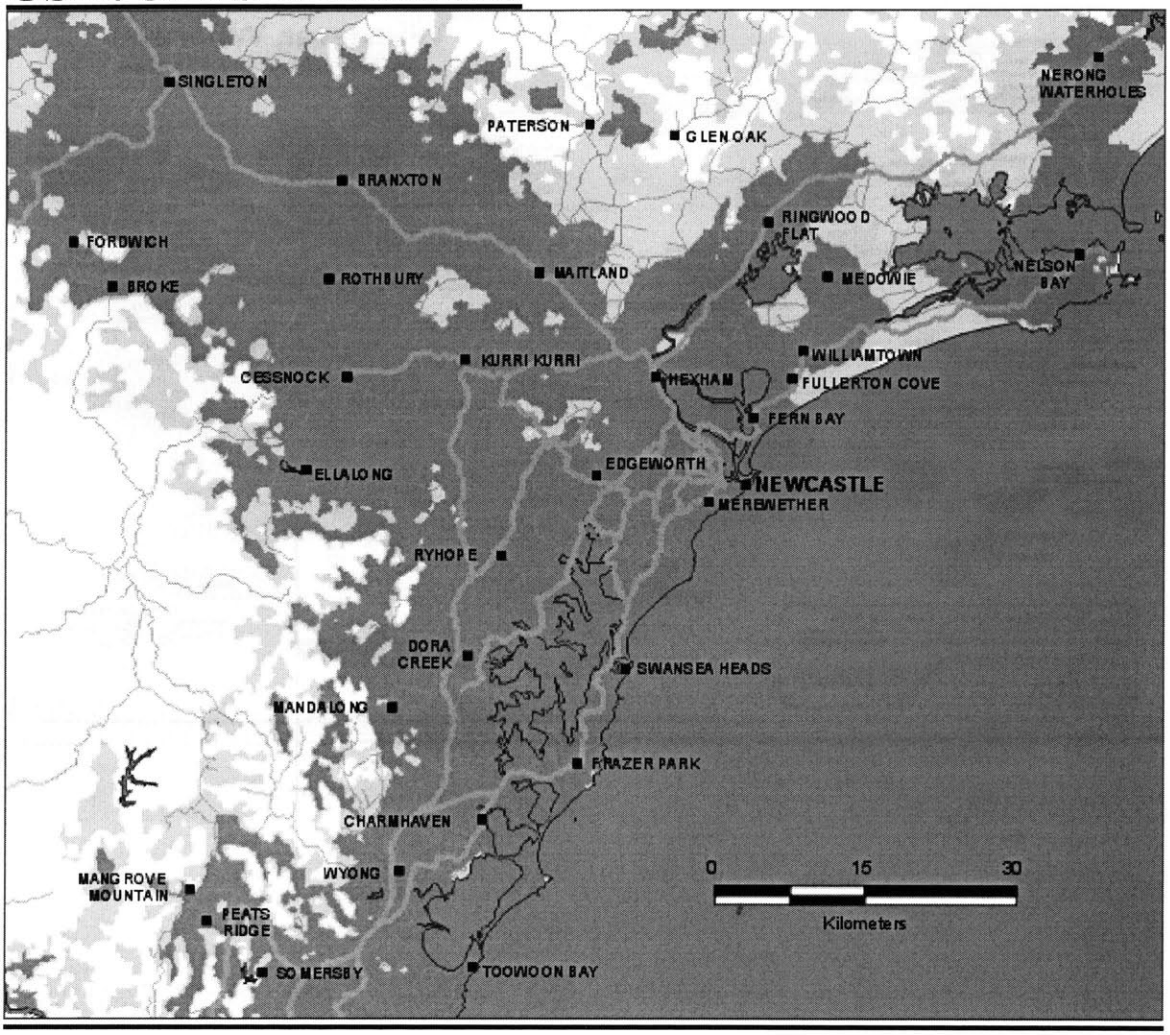
Conclusion

Thank you for your consideration of these projects. These purchases will be beneficial not only to the 4 MEng IT students involved with STEFS, but also the 2 MEng Environmental students and the 13 Environmental Engineering undergraduates. We would like to purchase these products as soon as possible in order to ensure we can properly integrate them before the rapidly approaching trip to Australia.

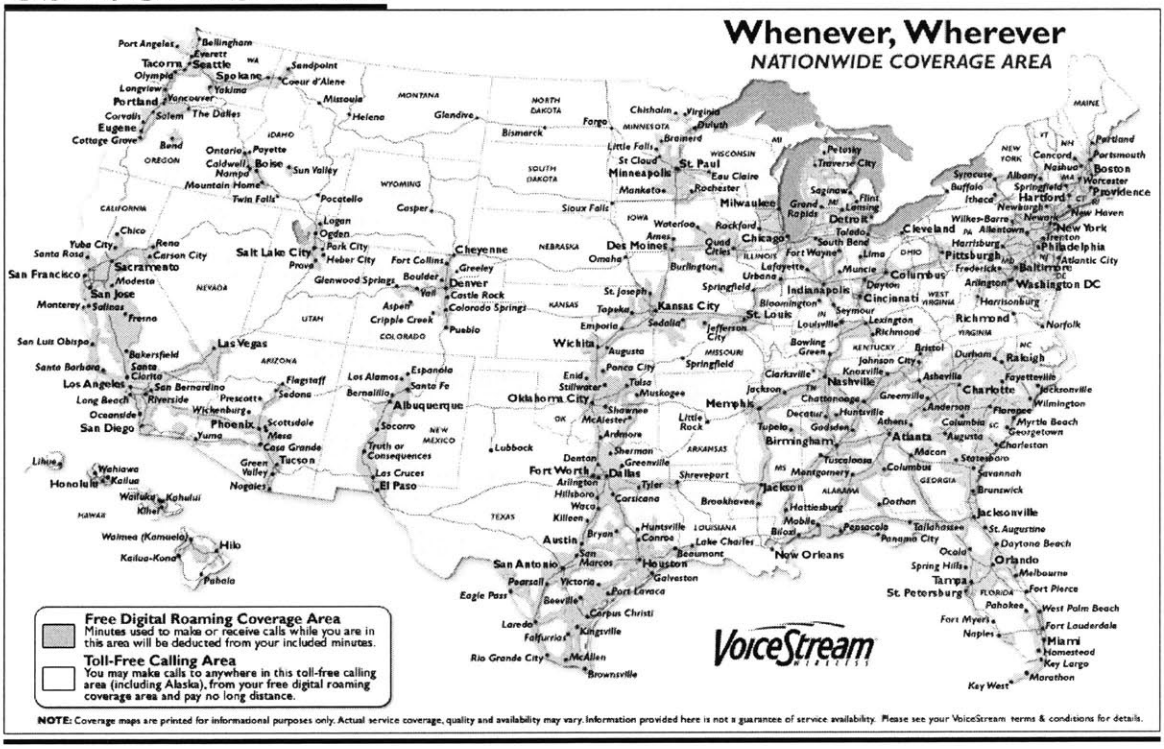
The total reduction in cost from the original version is almost $2000.

Sincerely,
Russ Spieler
w/ recommendations by Kan Liu
MEng IT
For the STEFS MEng Team

Appendix I.I
Full Size Telstra Coverage Map
GSM/GPRS In Australia



Appendix I.II
Full Size VoiceStream Coverage Map
GSM/GPRS In US


Whenever, Wherever
NATIONWIDE COVERAGE AREA
Free Digital Roaming Coverage Area
Minutes used to make or receive calls while you are in this area will be deducted from your included minutes.
Toll-Free Calling Area
You may make calls to anywhere in this toll-free calling area (including Alaska), from your free digital roaming coverage area and pay no long distance.
VoiceStream
NOTE: Coverage maps are printed for informational purposes only. Actual service coverage, quality and availability may vary. Information provided here is not a guarantee of service availability. Please see your VoiceStream terms & conditions for details.

Appendix I.III
Pricing for Qualcomm GSP1600 Satellite Phone ($1624)

The only Satellite phone for use in both the US and Australia (as well as around the world for future uses of this product) is the Qualcomm GSP1600 Tri-Mode Handset with available service from Globalstar. With the GDCKIT Data Cable Kit, this phone can connect to the laptop (via serial port) and send back data to our server from virtually anywhere on the planet. We will be able to test it in the US and use it in Australia.

The proposed spending is as follows (all from Globalstar 1.877.SAT.PHONE**):**

1 x Qualcomm GSP1600 Tri-Mode Handset	$899.00
1 x GDCKIT Data Cable Kit	$69.95
1 x Activation Fee	$50.00
1 x Shipping	$20.00
~~7 x 1 Month Globalstar Service charges (100mins)~~	~~$119.95/mont~~ ~~$839.65 total~~
7 x 1 Month Globalstar Service charges (50mins)	$69.95/mont $489.65 total
40 x Estimated Minutes while in Australia	$2.39/min $95.60 total
~~Total for Field Laptop to Web Server~~	~~$1974.20~~

Total for Field Laptop to Web Server
$1624.20

Appendix I.IV Price for Ericsson T28W ($500)

1 x Ericsson T28W GSM Tri-Mode (1900/1800/900MHz) Phone	$79.99 (VoiceStream)
1 x Ericsson Infrared Modem	$59.95 (VoiceStream)
1 x SIMM Card	$30???
12 x 1 Month VoiceStream Service Charges (60mins/500mins/month)	$19.99/month $239.60 total (VoiceStream)
40 x Estimated mins while in Australia	$0.44/min $17.60 total (VoiceStream)
Total for Field Laptop to Web Server	$427.14 + tax and shipping
Approximately	**$500**